NAVFAC
Naval Facilities Engineering Command
Engineering Service Center

# Computational Fluid Dynamics (CFD) For JLOTS Applications

JLOTS Symposium 2004

27 – 29 Jan 04

Duck, NC

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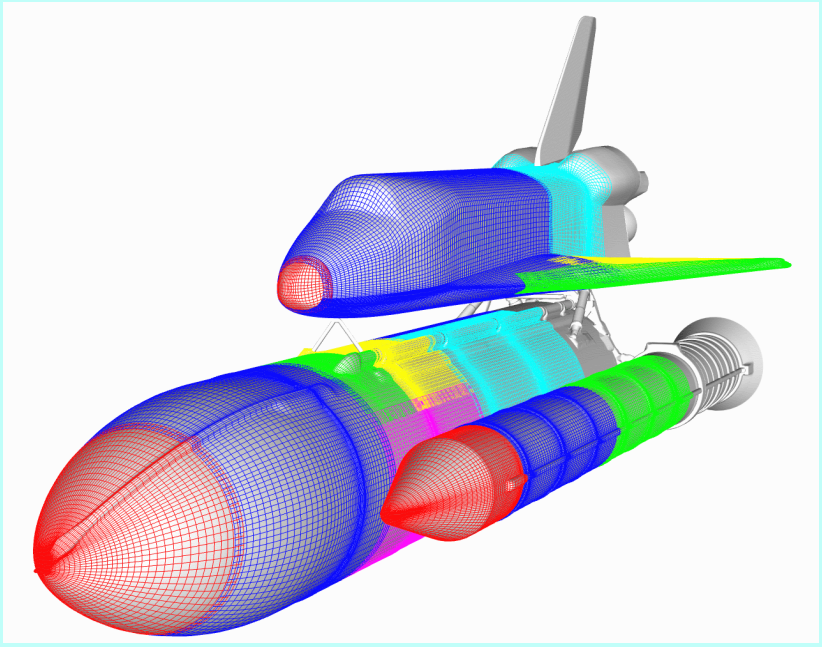
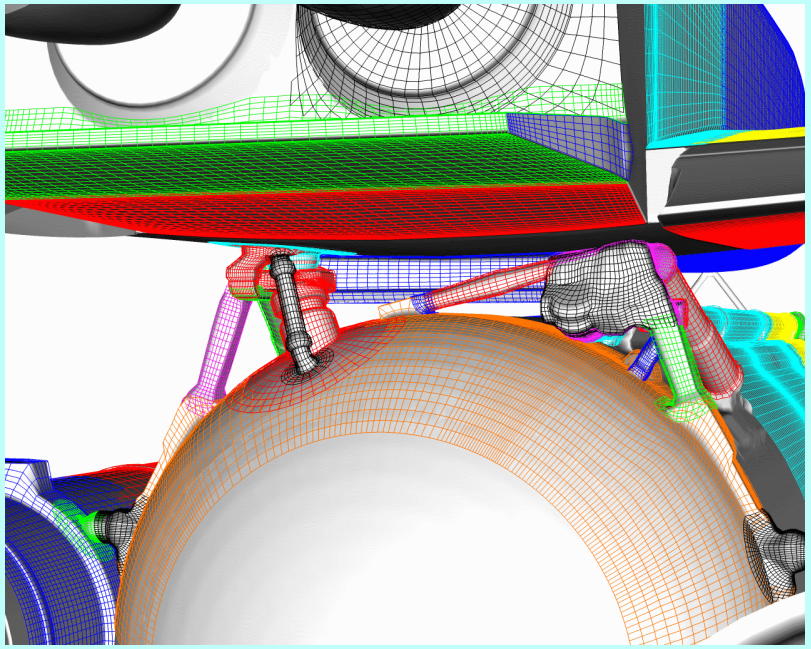
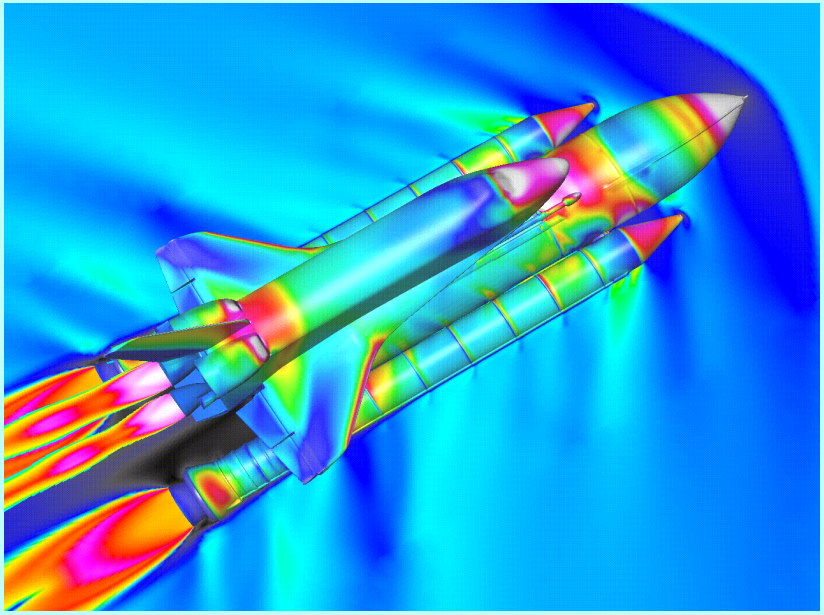
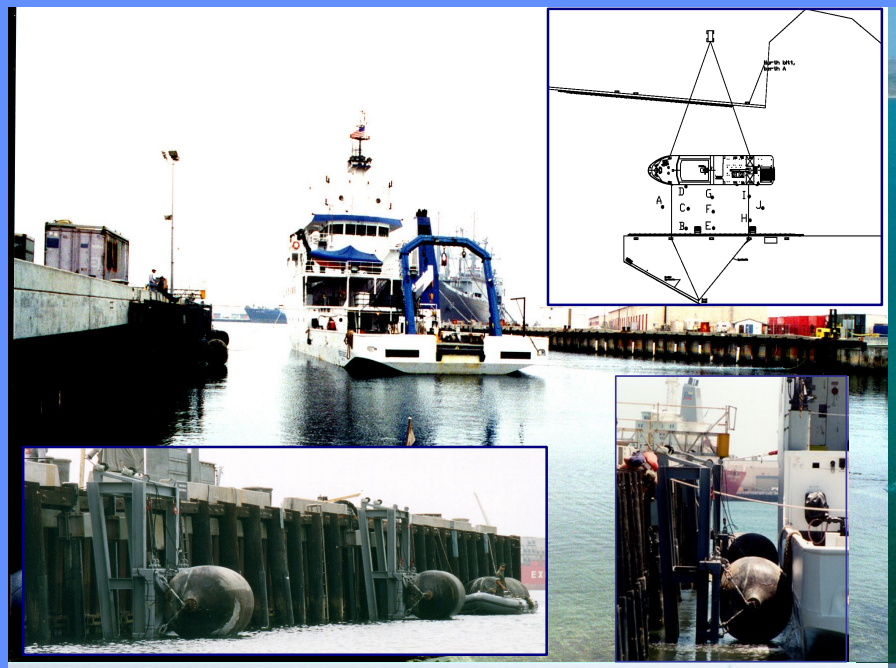


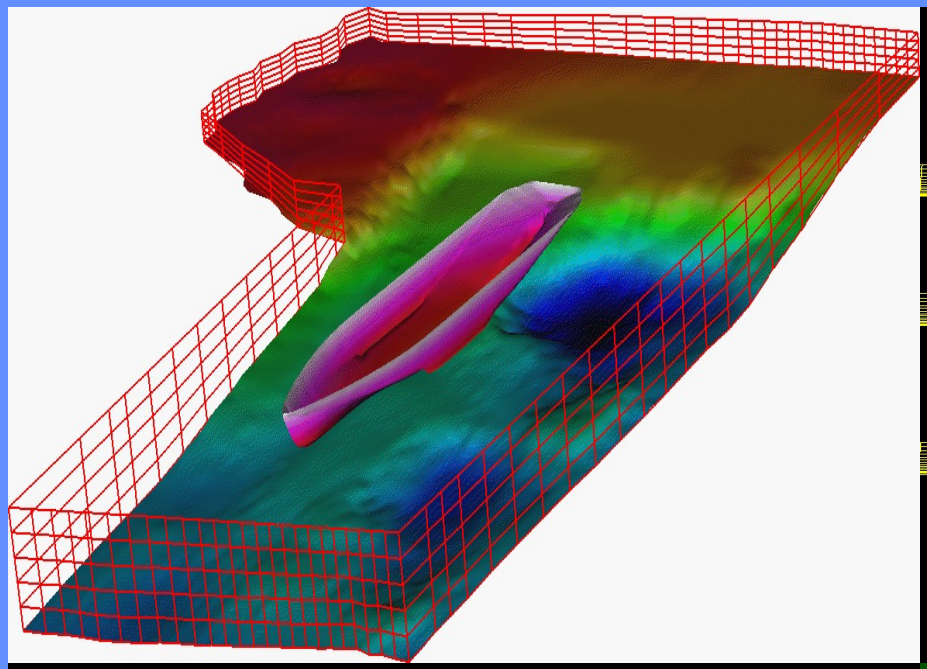


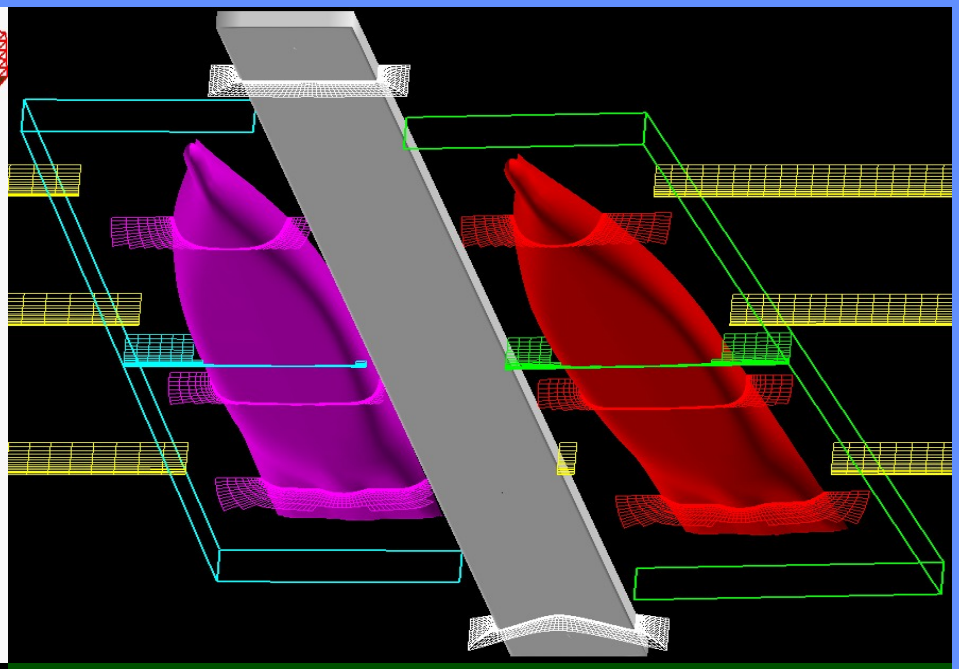


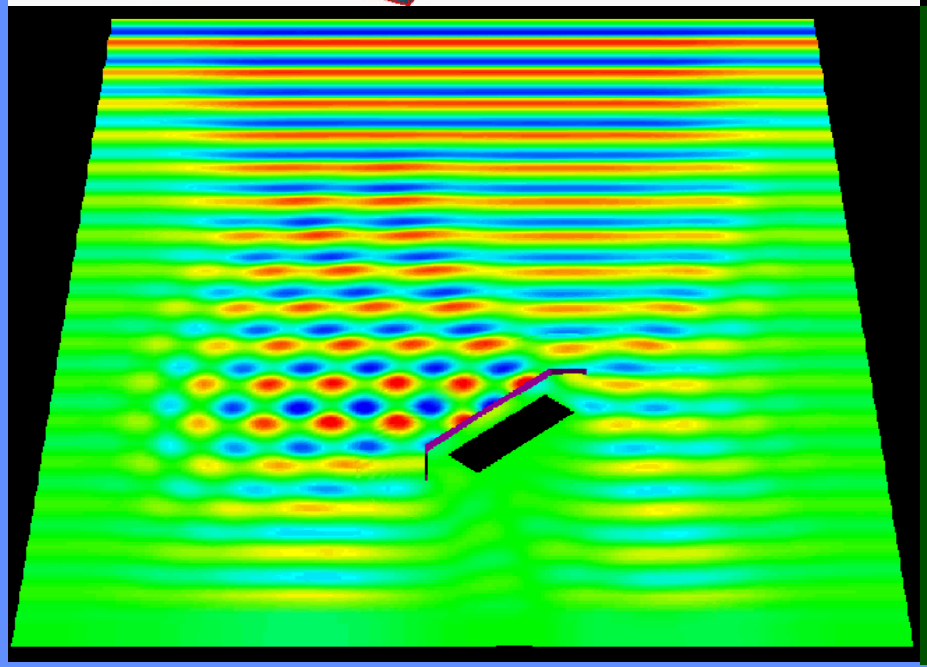
- Accuracy
- Completeness
- Cost Reduction

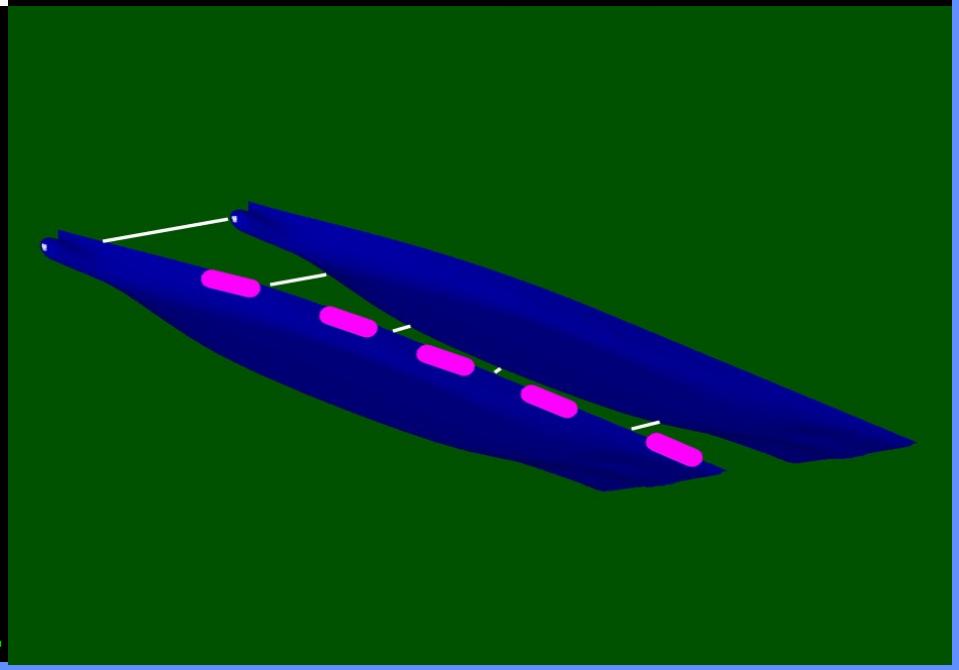


NAVAL FACILITIES ENGINEERING SERVICE CE







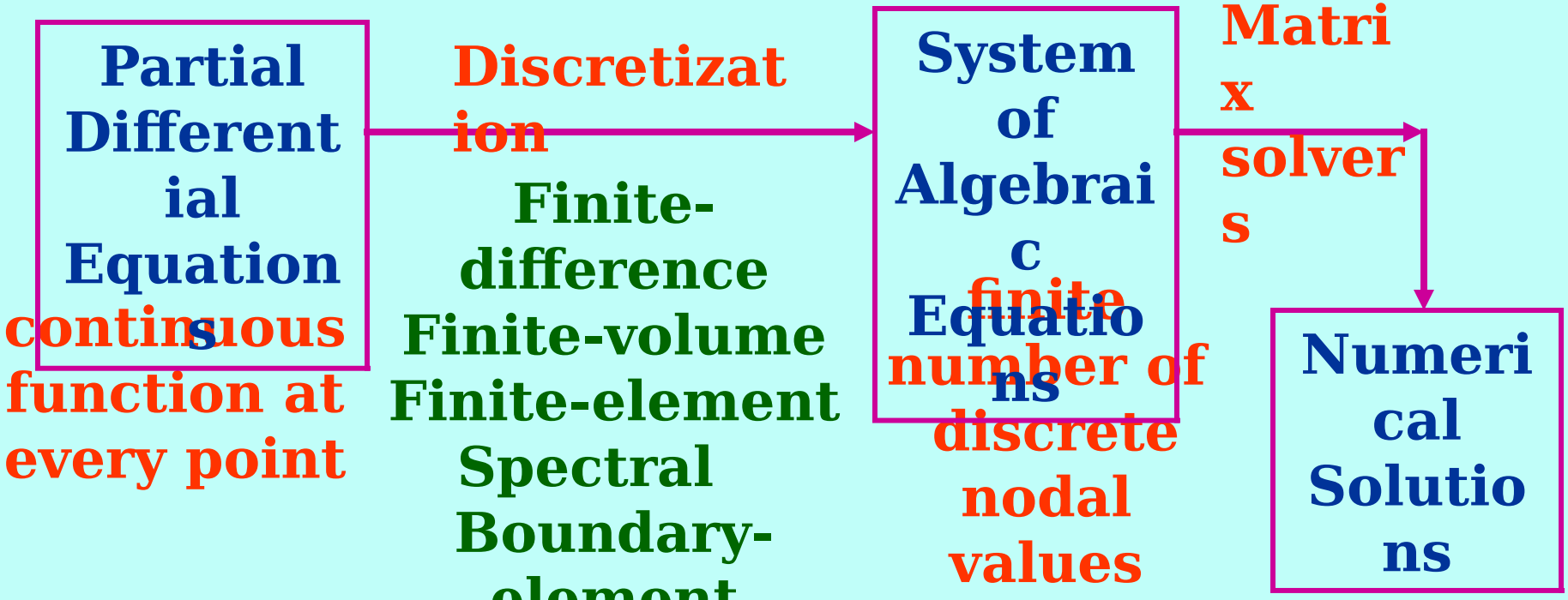


# Fluid Mechanics

- Theoretical Fluid Dynamics
- Experimental Fluid Dynamics (EFD)
  - Wind tunnels
  - Towing tank, wave tank, & hydraulic model
  - Field experiments
- Computational Fluid Dynamics (CFD)
  - Numerical algorithms, Computers, Graphics, Animations

# Overview of CFD

**Discretization - Numerical Methods Auxiliary (initial/boundary) conditions**



# CFD model at NFESC

- RANS: Chimera, RANS viscous flow solver
- CHAMPS: Chimera Potential flow solver
- COSMA: 3D, multi-body, fully coupled motion analyzer
- Utility routines:
  - GRIDGEN (numerical grid generator, commercial code)
  - PEGSUS (data management code, USAF)
  - TECPLOT (image processor, commercial code)

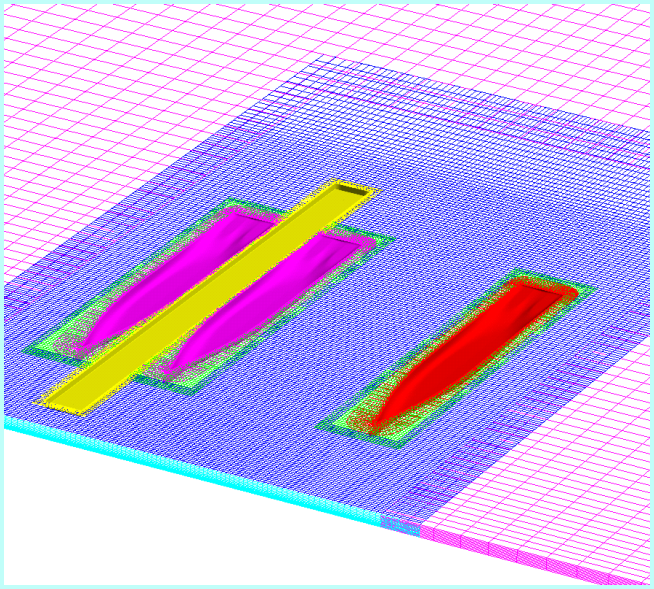
# Chimera RANS Solver

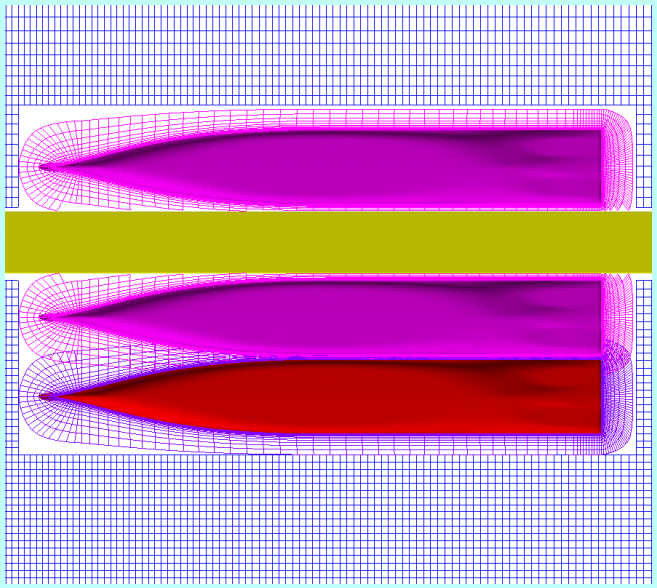
- Unsteady Compressible/Incompressible Navier-Stokes Equations
- Curvilinear, Moving Coordinate System
- Chimera Domain Decomposition
- Extensive turbulence models
- Multiblock, Multigrid Flow Solver
- Interactive GRIDGEN for Composite Grids
- Embedded, Overlapped, or Matched Grids
- Automatic regridding for Moving Grids
- PEGSUS Interpolation for Composite Grids

# CHAMPS

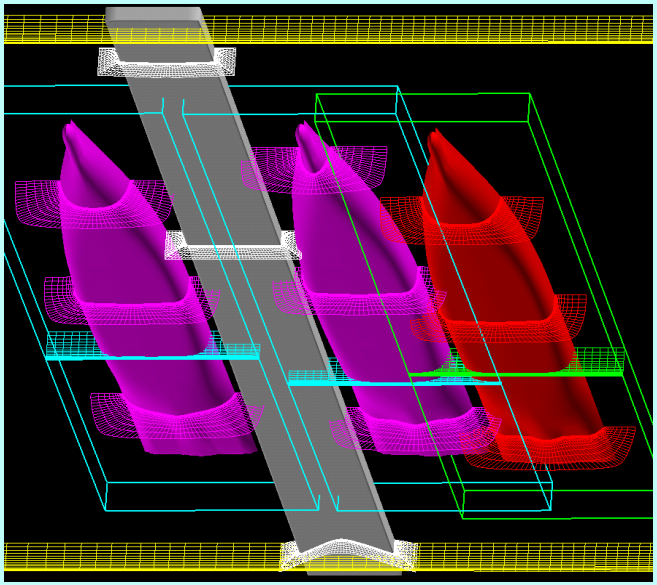
CHimera finite-Analytic Method for Potential-flow Solver

- Laplace equation for velocity potential
- Curvilinear, moving coordinate system
- Chimera domain decomposition
- Finite-analytic method
- Nonlinear free surface boundary conditions
- Data management for maximum flexibility





# Chimera Grids



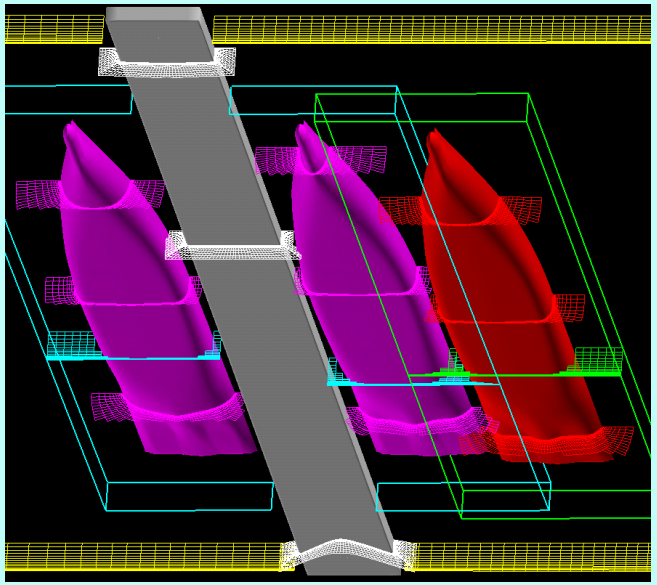
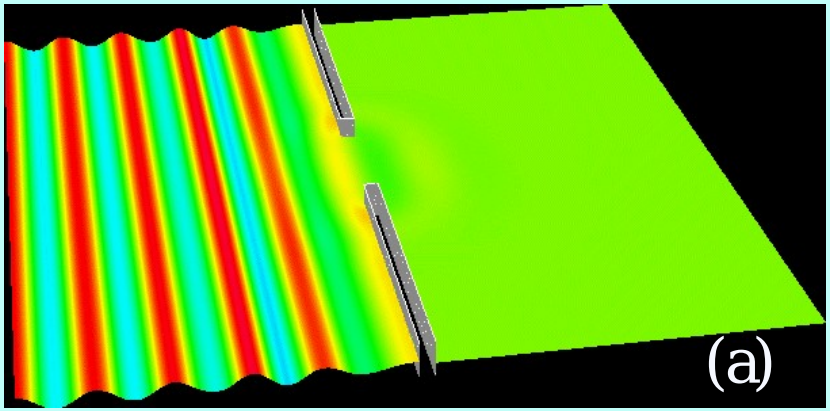
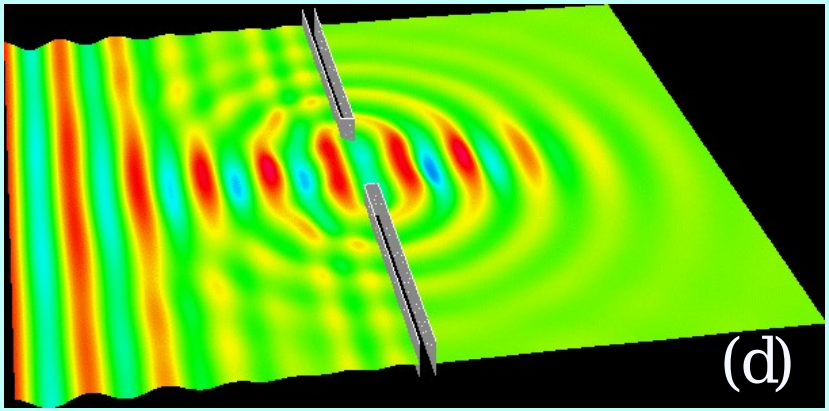
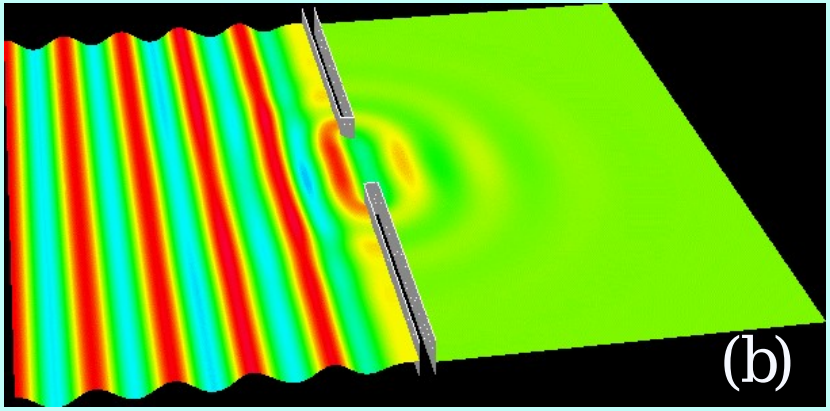


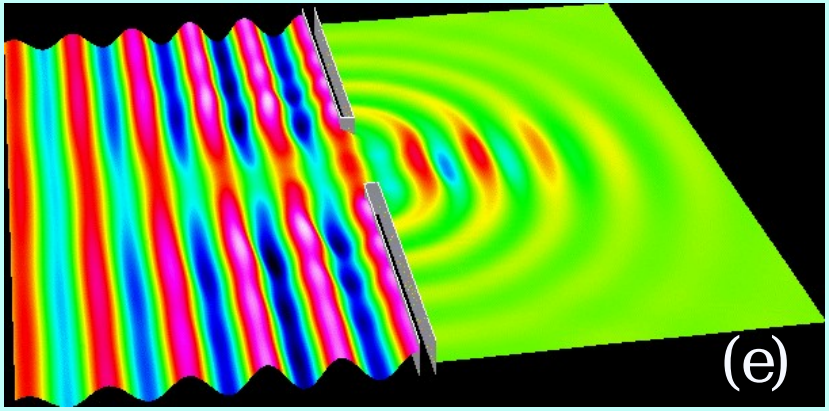
Fig. 2 – Solution domain and numerical grids

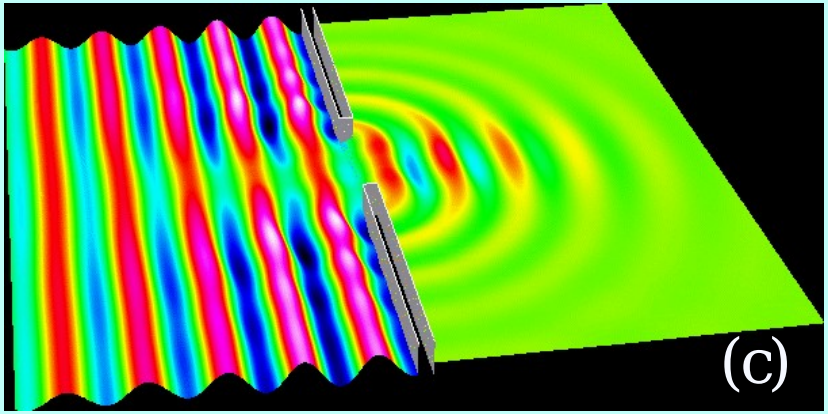
# Diffraction

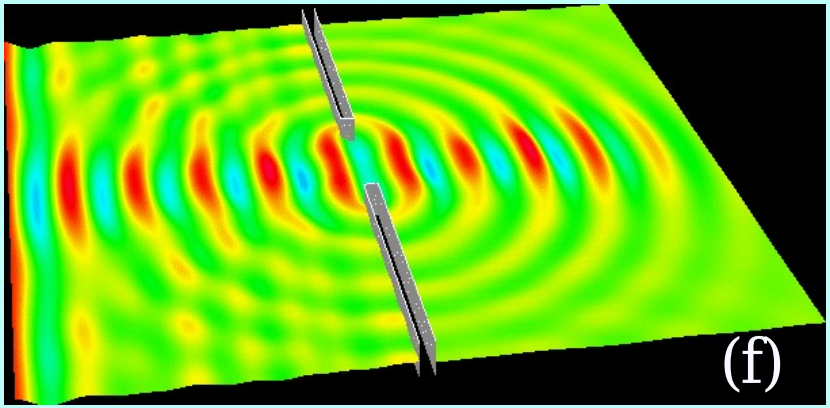


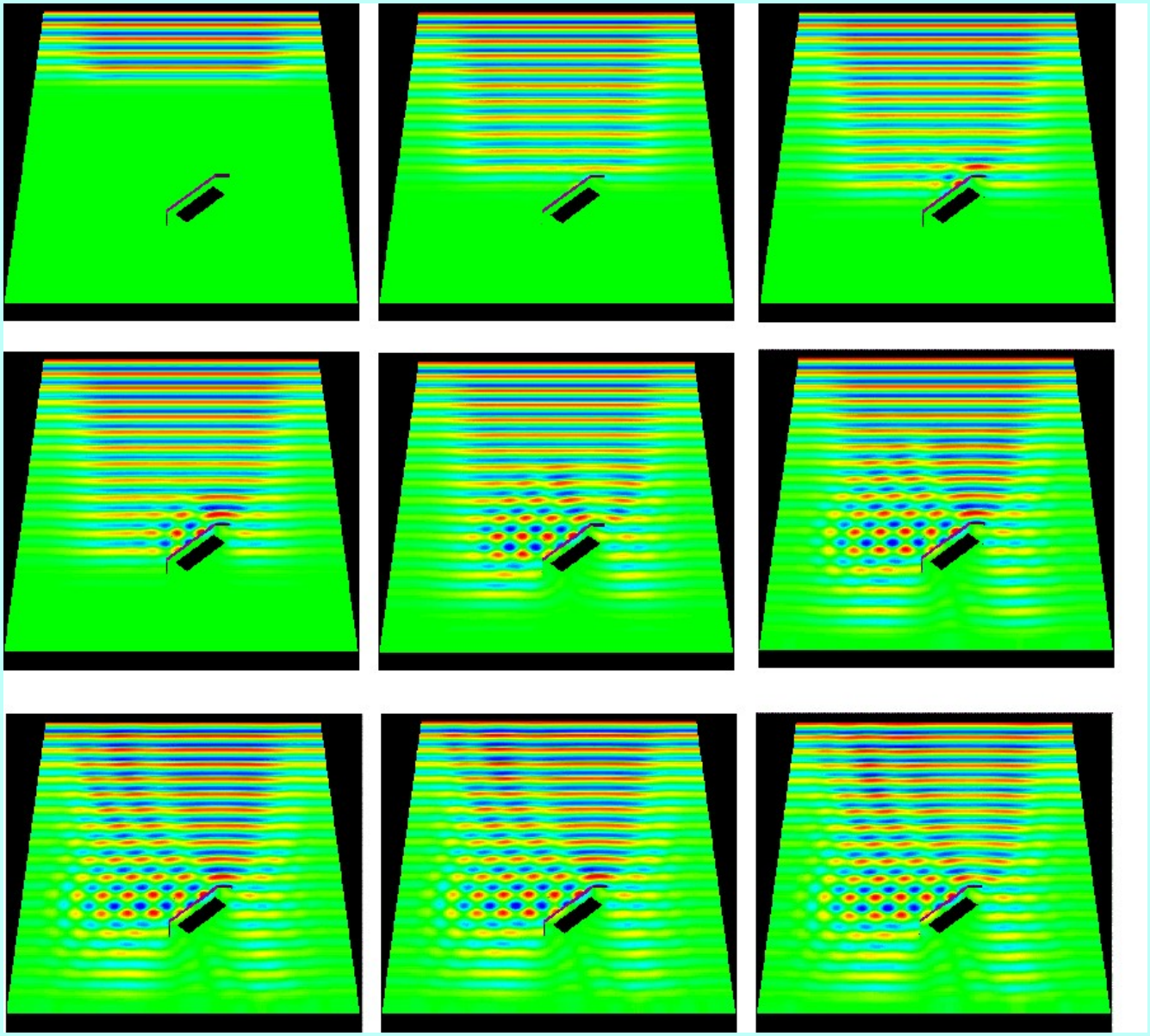



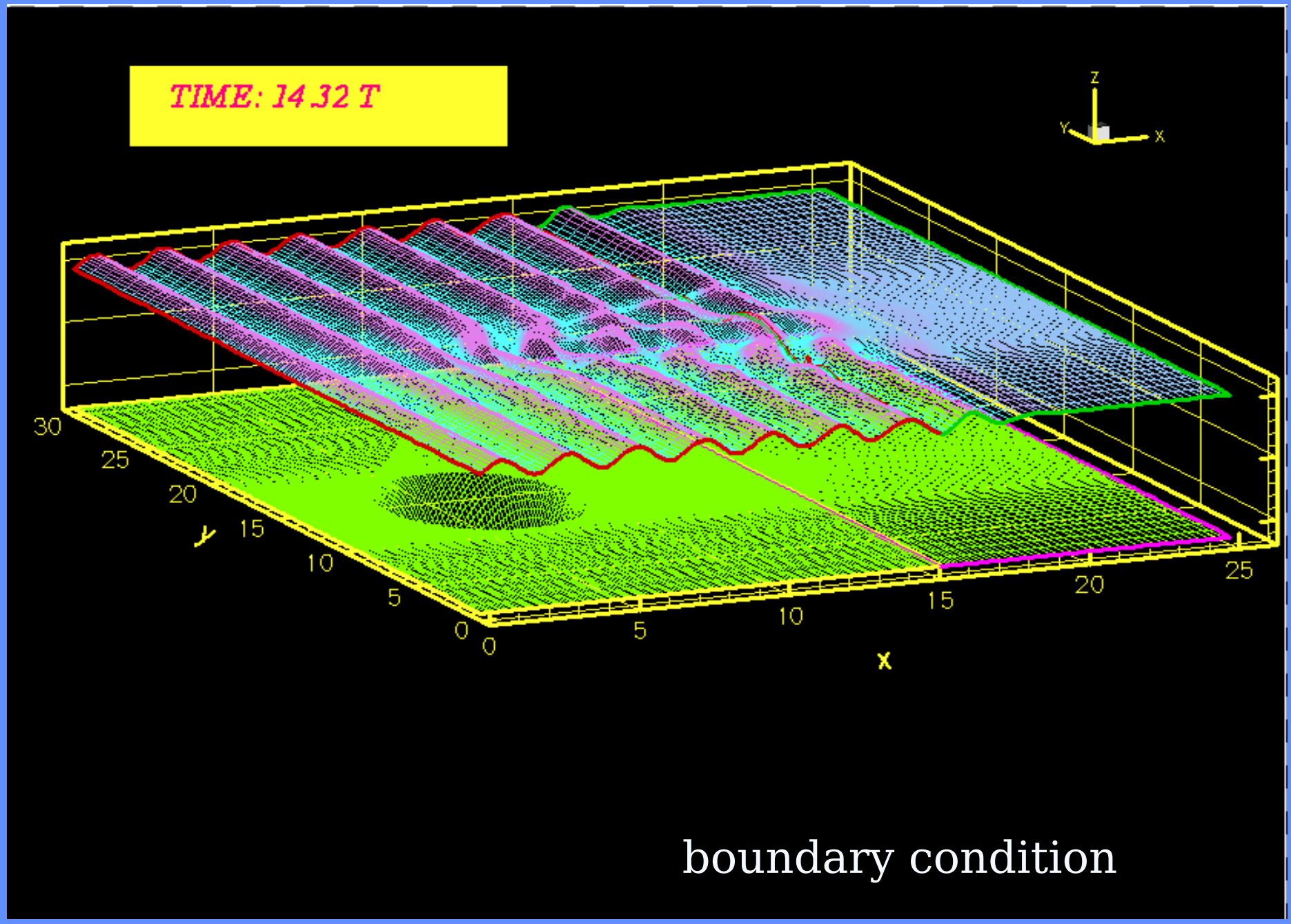



Reflection



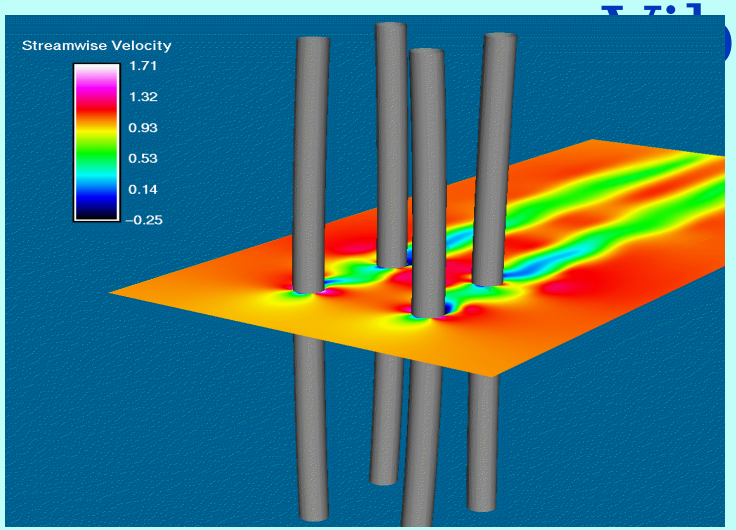
# Fisherman Wharf, San Francisco Bay

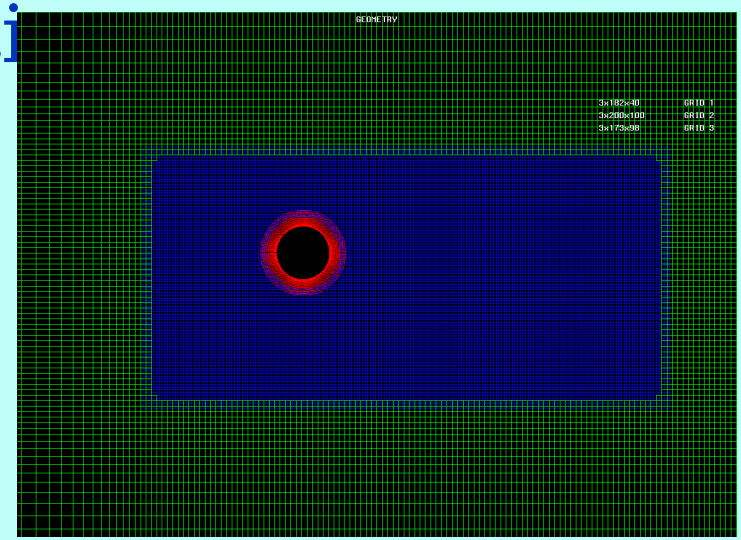

TIME: 14.32 T
Z
Y
X
30
25
20
y
15
10
5
0
0
5
10
15
20
25
x
boundary condition

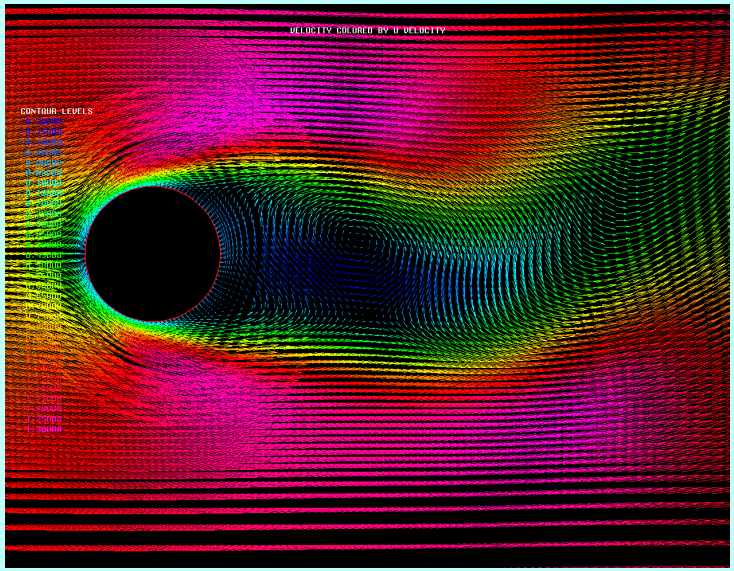
# Why CFD ?

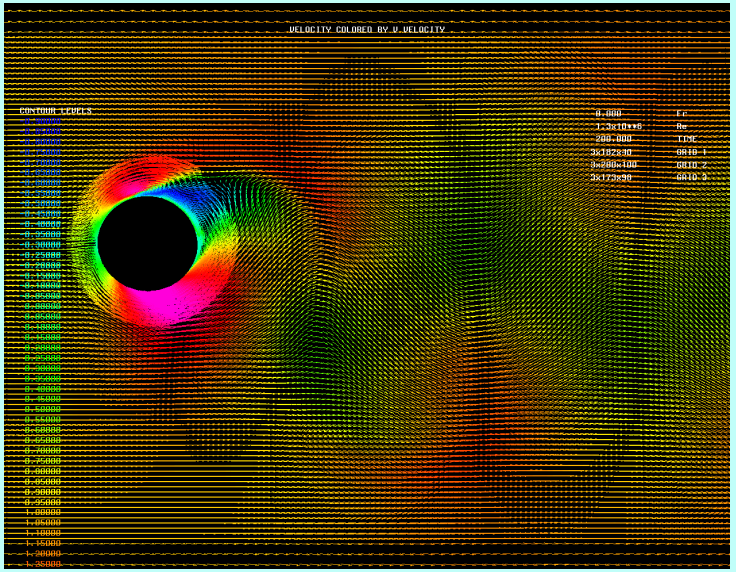
- Accuracy, completeness, & details
- Safety concerns
- Physical restraint
- Non-existence entities
- Complex system in congested water
- Uncharacteristic application
- Information expansion
- Cost, schedule, or facility constraints

# Vortex Shedding and Vortex-Induced Vibrati



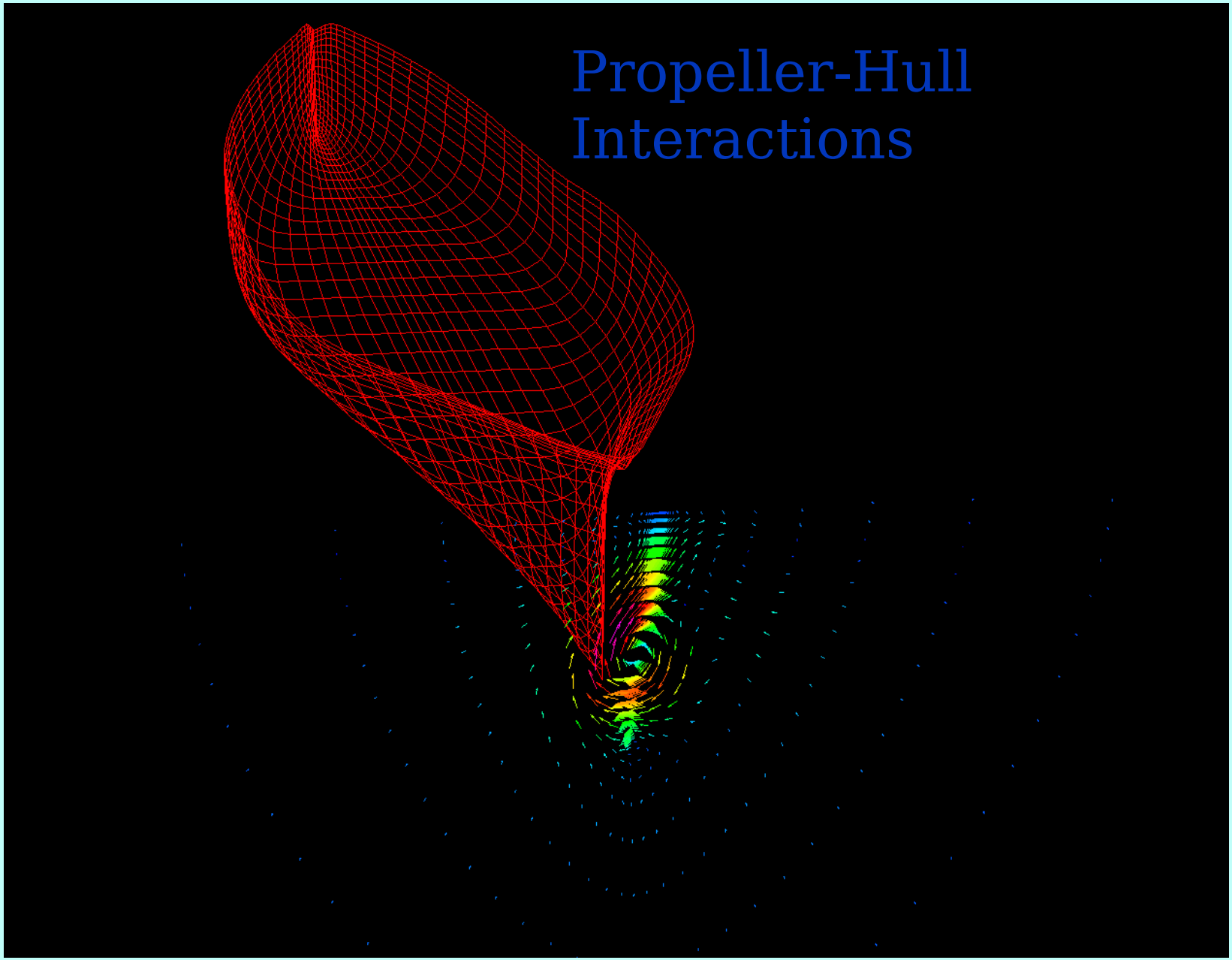




**Stationary cylinder**

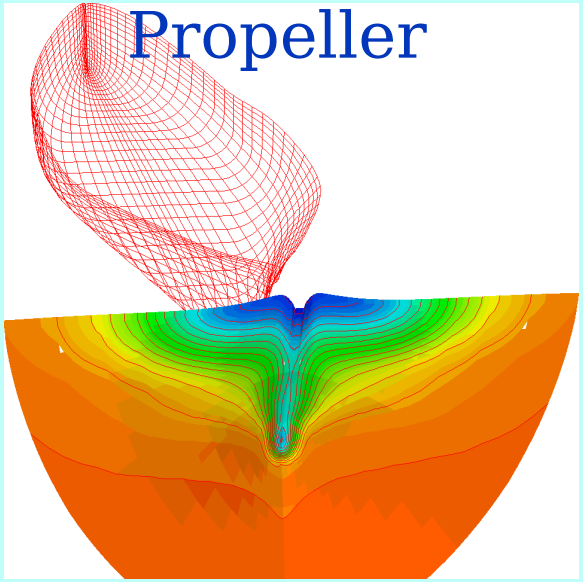
**Vibrating Cylinder**

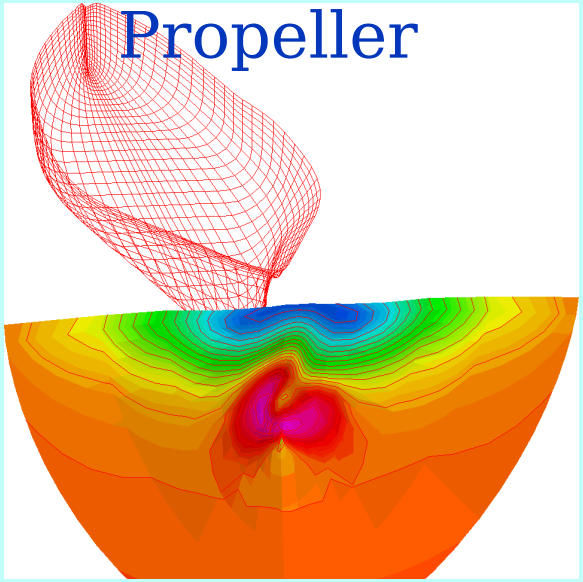

Propeller-Hull
Interactions

Without Propeller

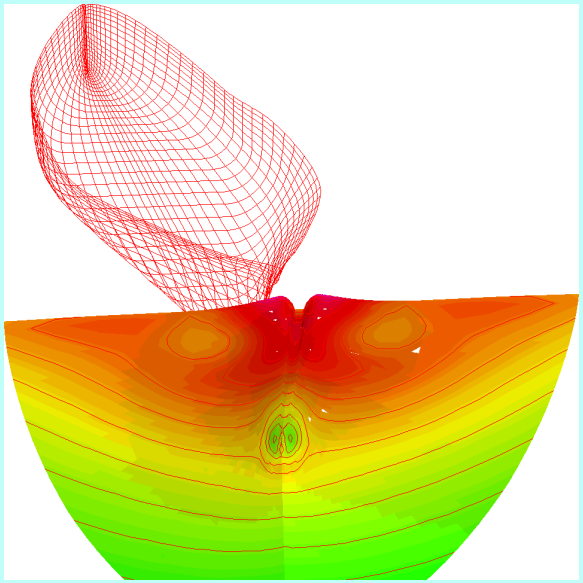
With Propeller

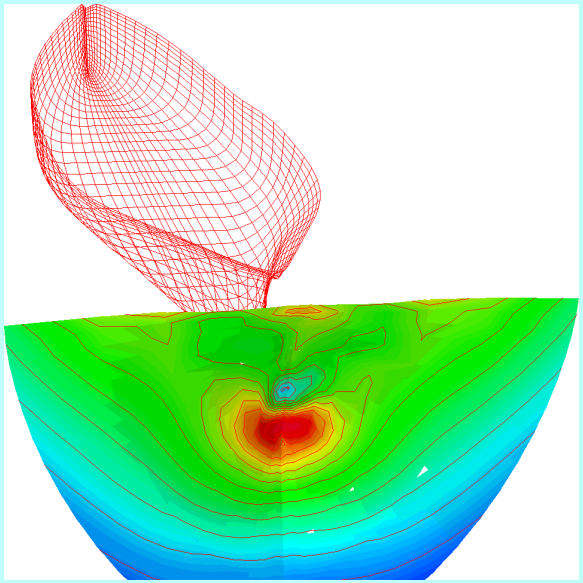
Velocity Contours

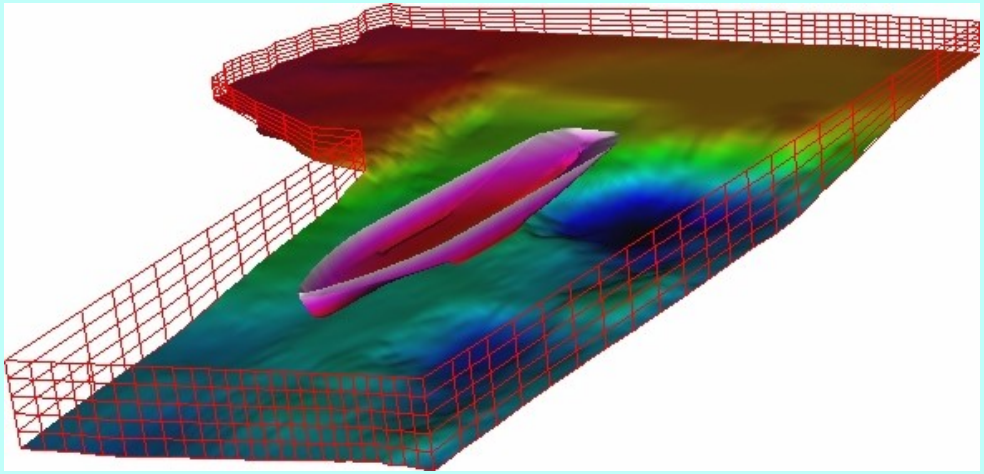


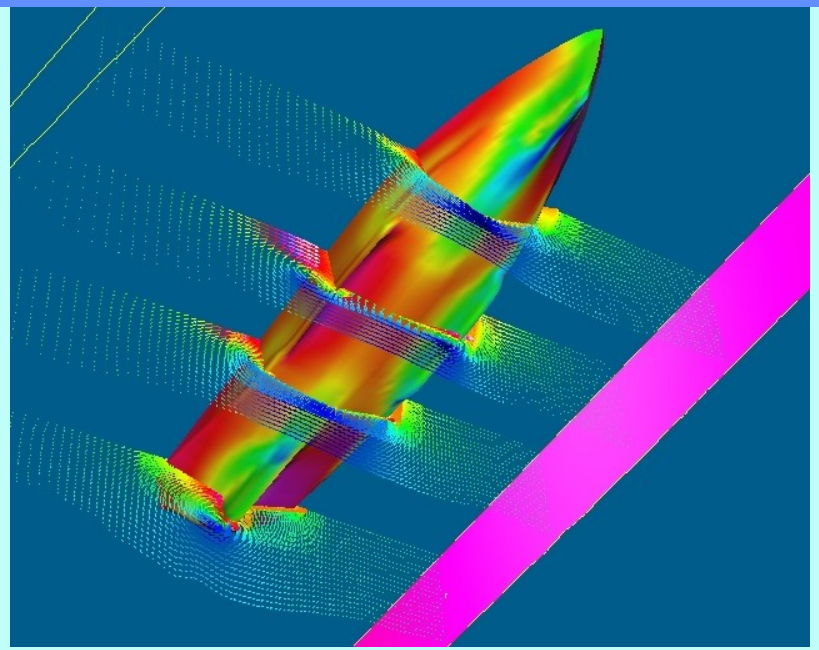


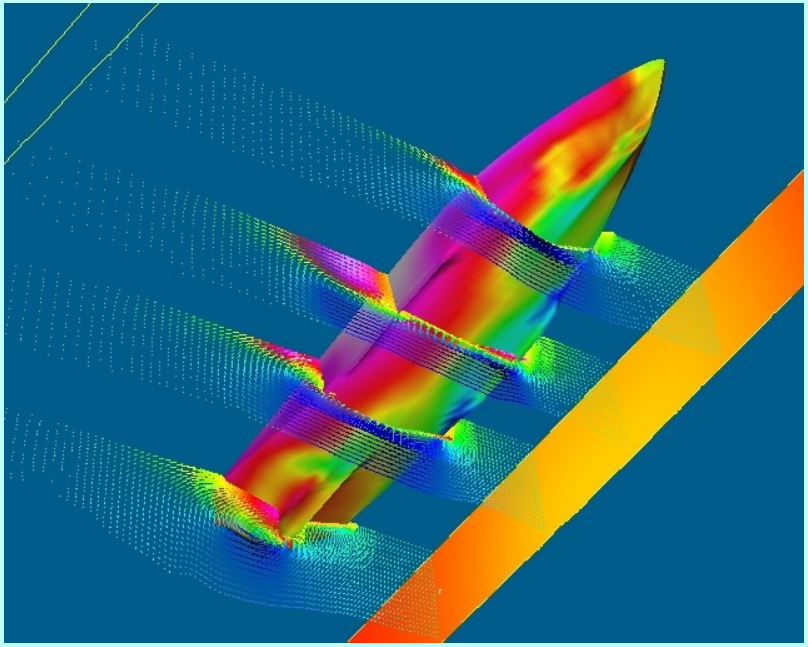
Pressure Contours

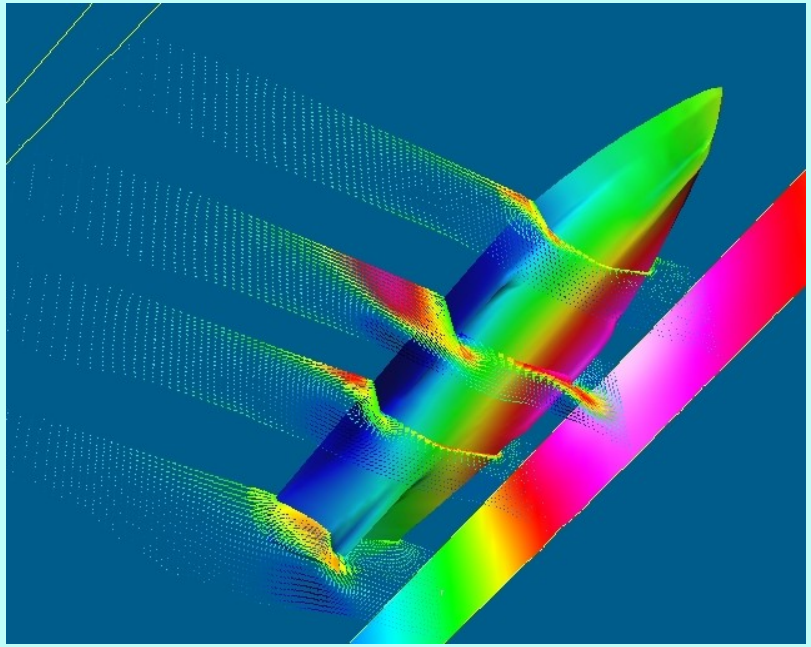




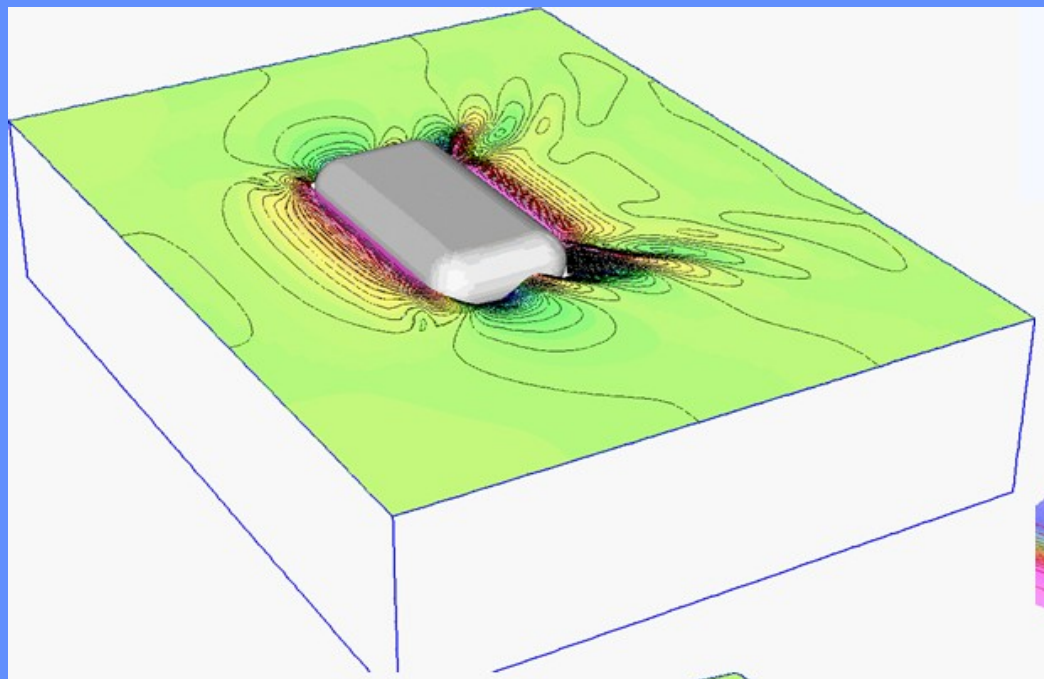


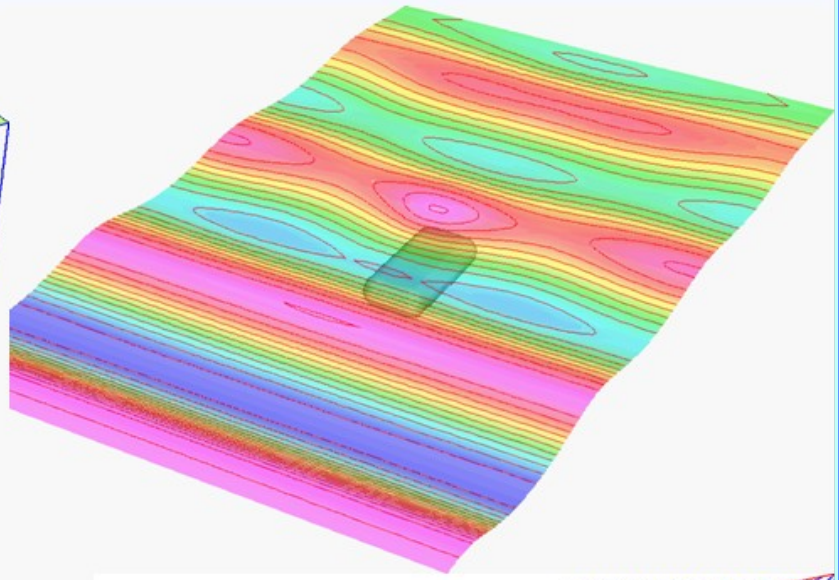


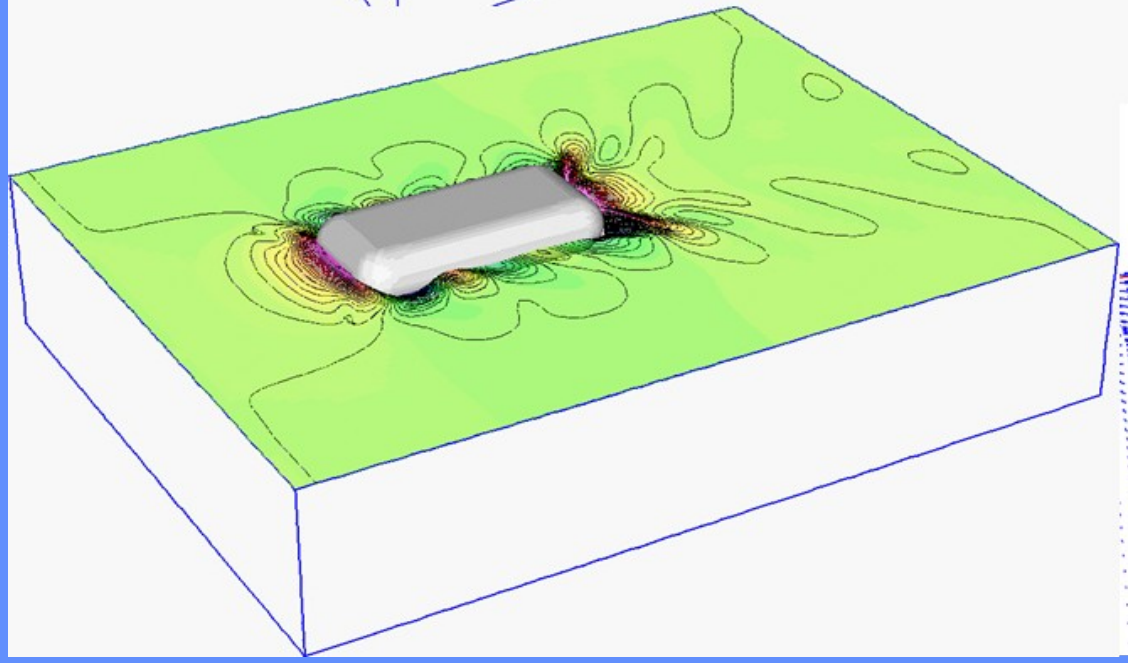


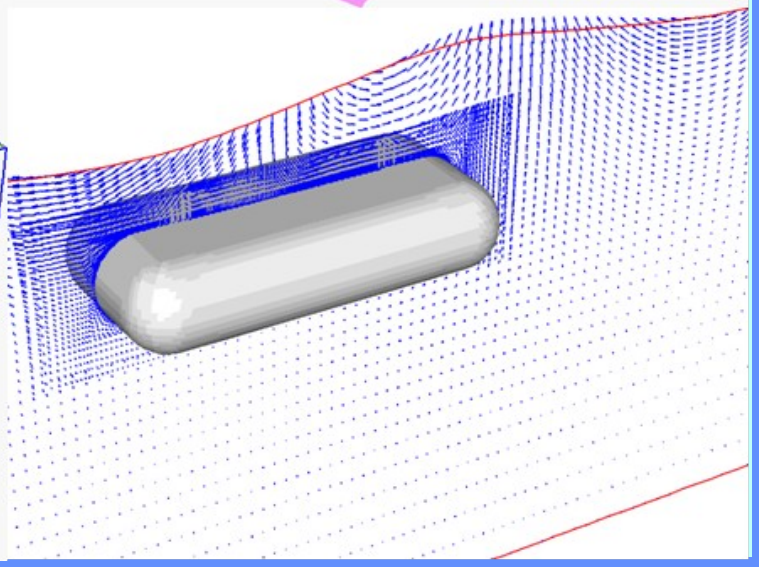


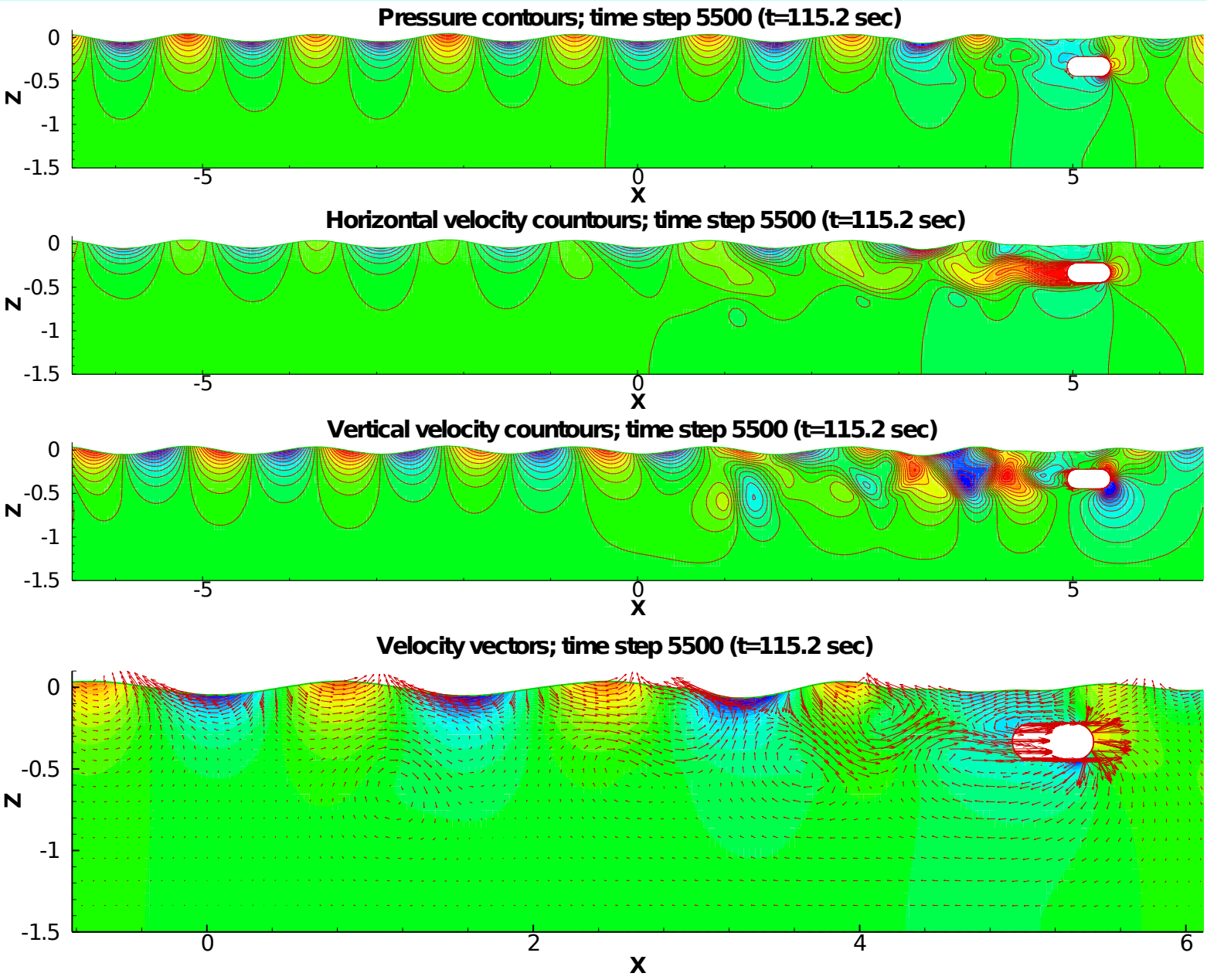
# Sea Cache



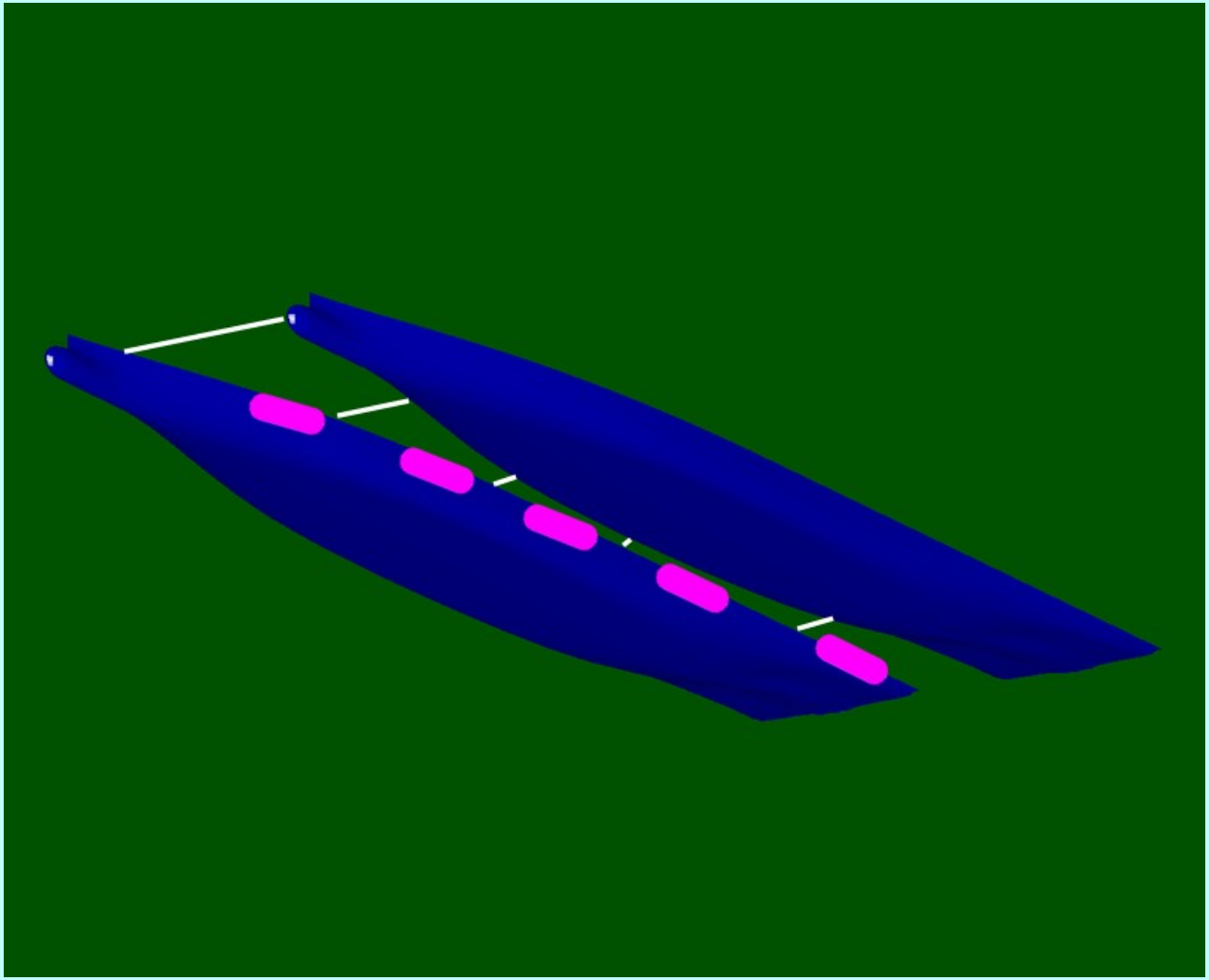


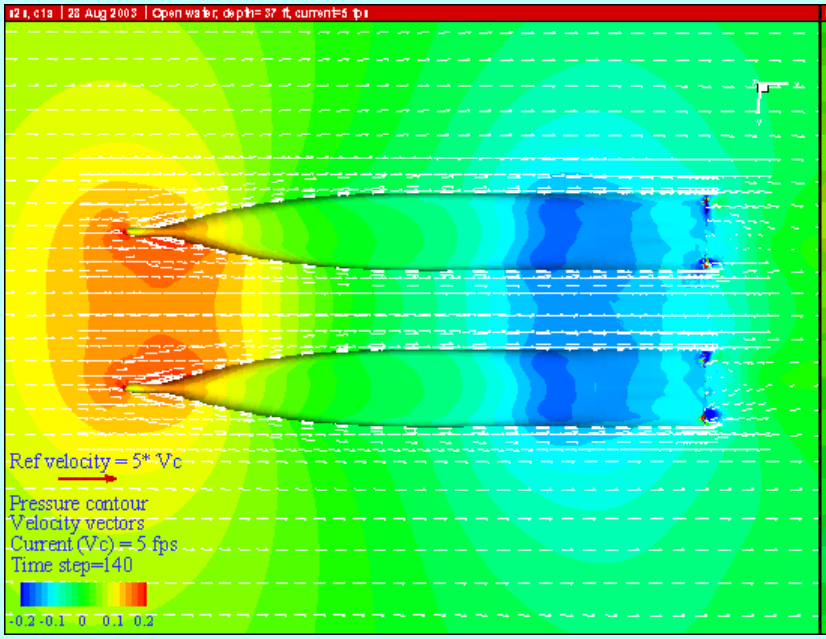


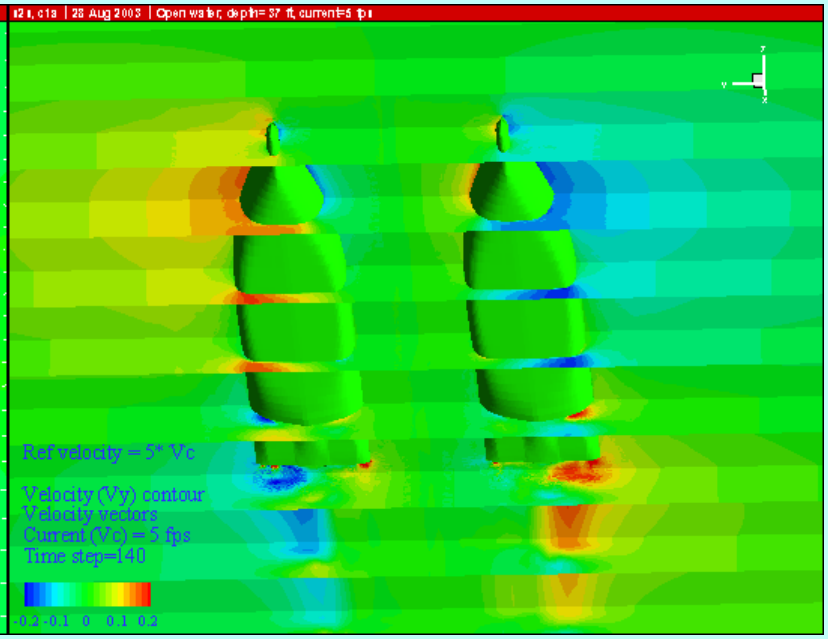


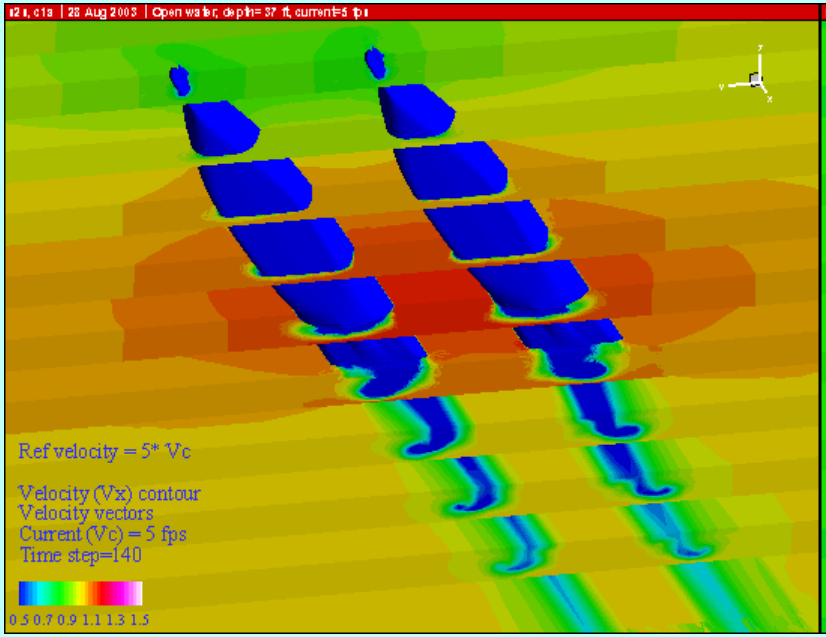

Pressure contours; time step 5500 (t=115.2 sec)
Horizontal velocity countours; time step 5500 (t=115.2 sec)
Vertical velocity countours; time step 5500 (t=115.2 sec)
Velocity vectors; time step 5500 (t=115.2 sec)
Z
X
0
-0.5
-1
-1.5
-5
5
2
4
6

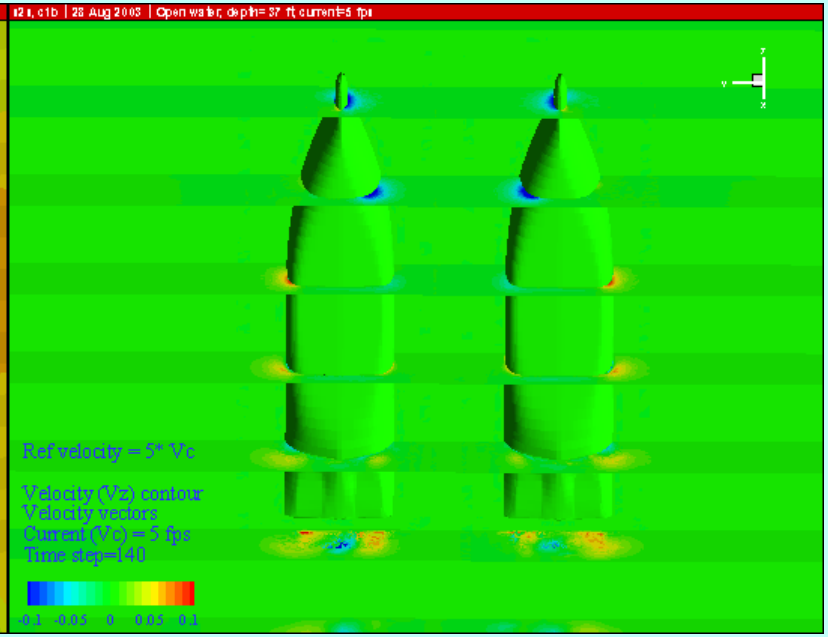
# Skin-to-Skin UNREP Scenario




s2 s, c1a | 28 Aug 2003 | Open water, depth= 37 ft, current=5 fps
Ref velocity = 5* Vc
Pressure contour
Velocity vectors
Current (Vc) = 5 fps
Time step=140
-0.2 -0.1 0 0.1 0.2

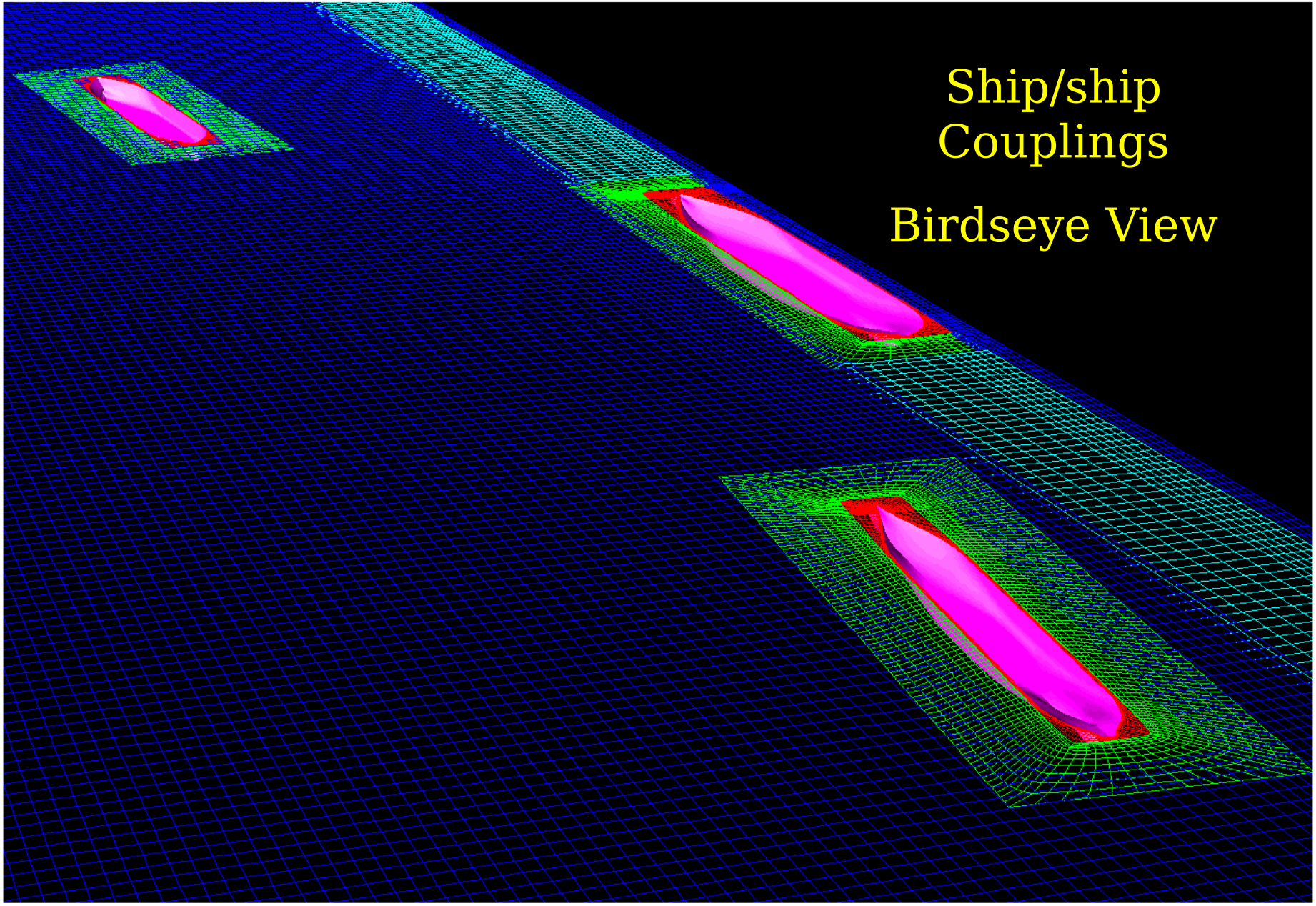

s2 s, c1a | 28 Aug 2003 | Open water, depth= 37 ft, current=5 fps
Ref velocity = 5* Vc
Velocity (Vy) contour
Velocity vectors
Current (Vc) = 5 fps
Time step=140
-0.2 -0.1 0 0.1 0.2

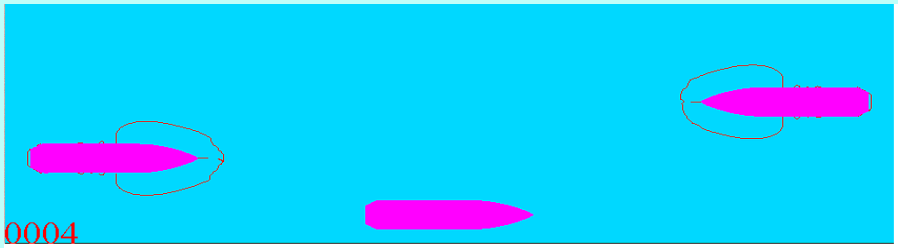

s2 s, c1a | 28 Aug 2003 | Open water, depth= 37 ft, current=5 fps
Ref velocity = 5* Vc
Velocity (Vx) contour
Velocity vectors
Current (Vc) = 5 fps
Time step=140
0.5 0.7 0.9 1.1 1.3 1.5


s2 s, c1b | 28 Aug 2003 | Open water, depth= 37 ft, current=5 fps
Ref velocity = 5* Vc
Velocity (Vz) contour
Velocity vectors
Current (Vc) = 5 fps
Time step=140
-0.1 -0.05 0 0.05 0.1

# S2 Sc 1a

time step: 140


Ship/ship
Couplings
Birdseye View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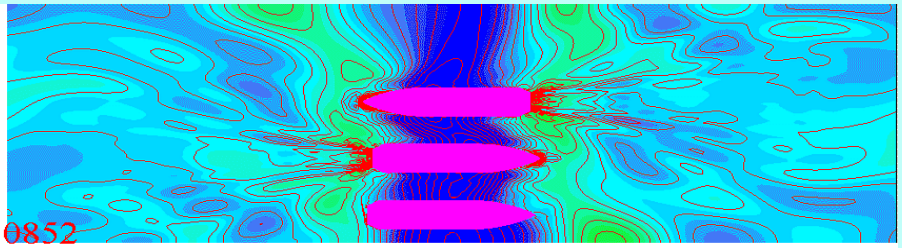
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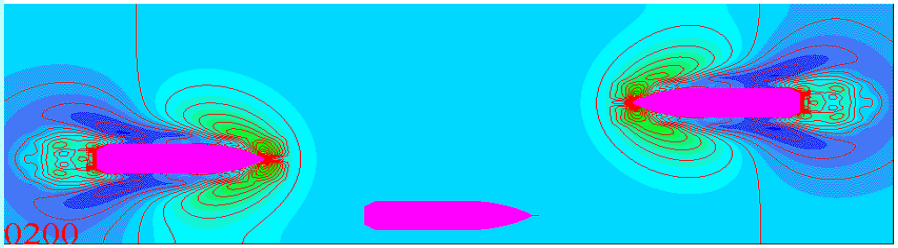
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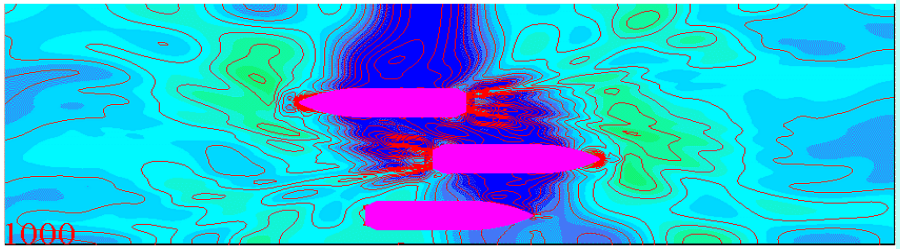
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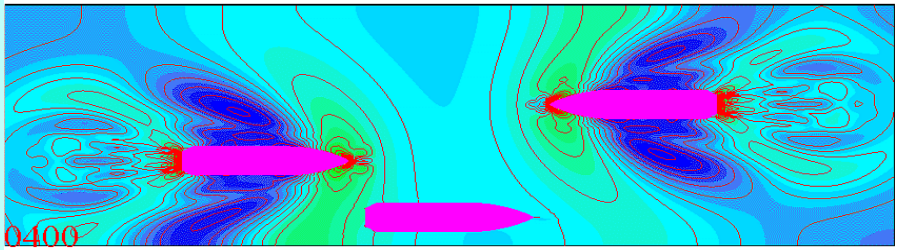
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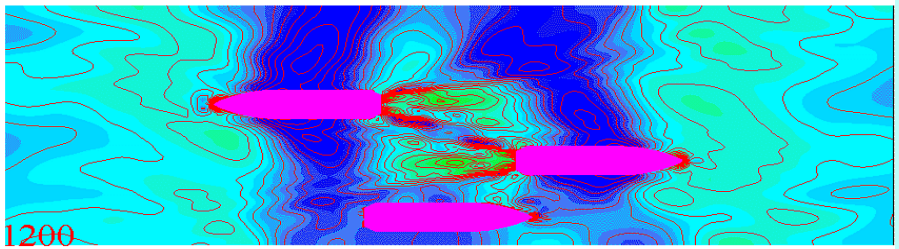
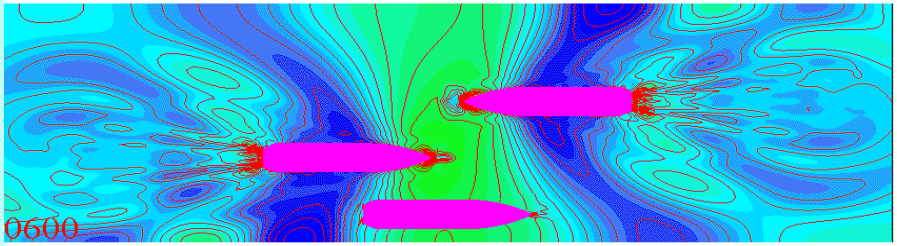

1200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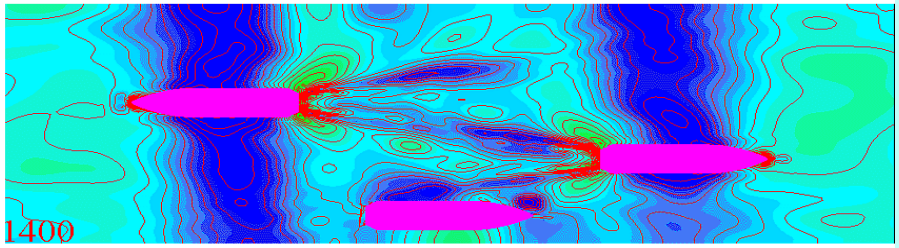
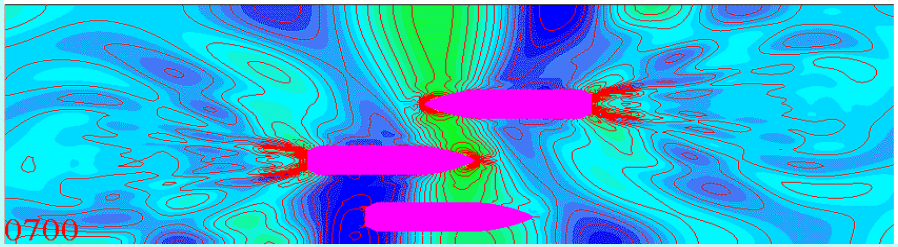

1400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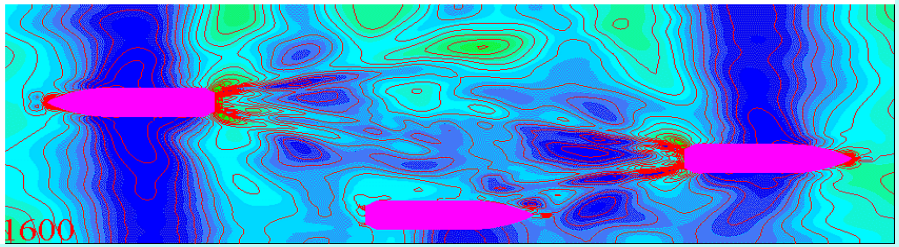
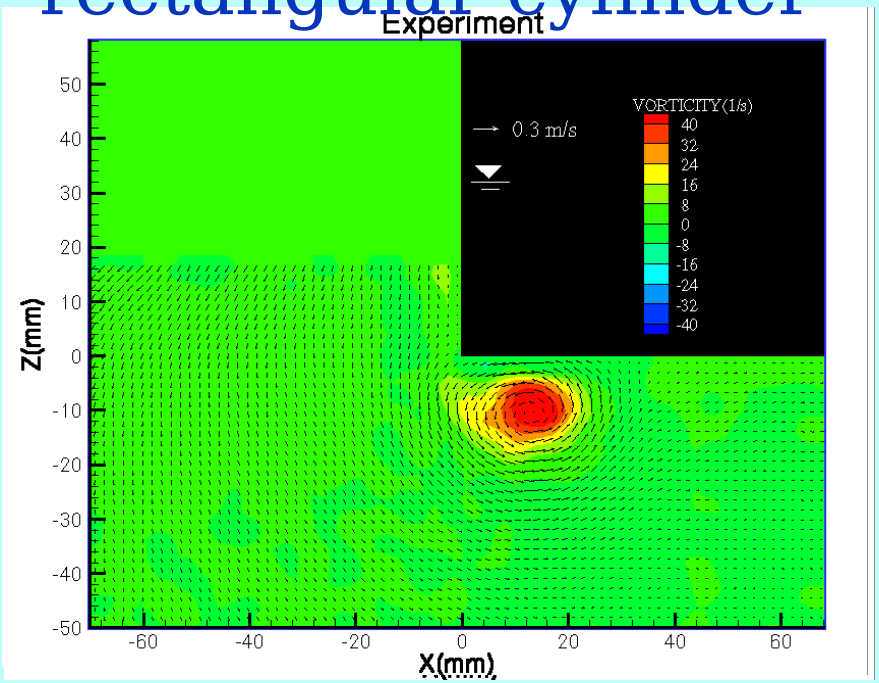
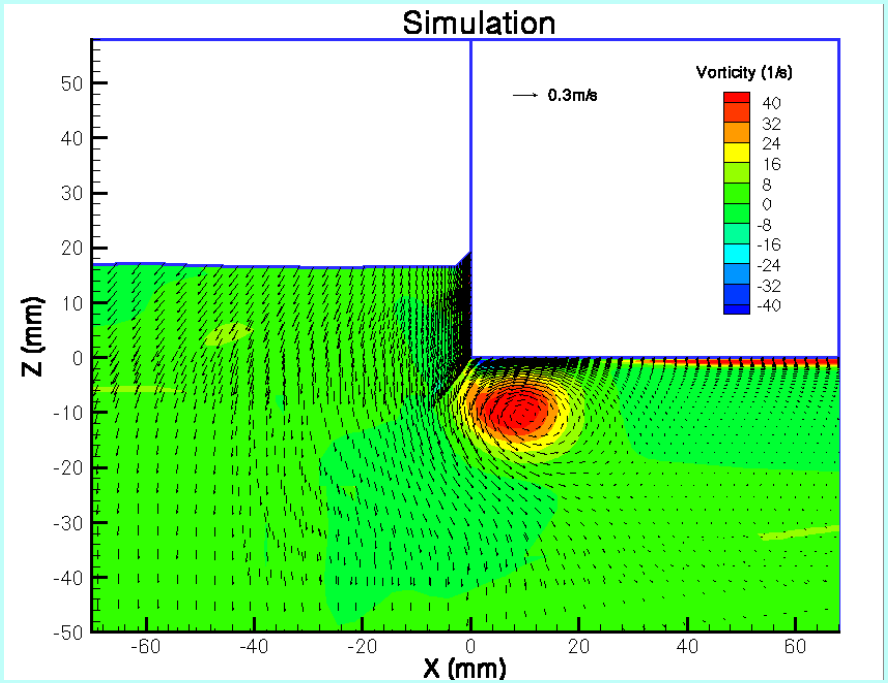

1600

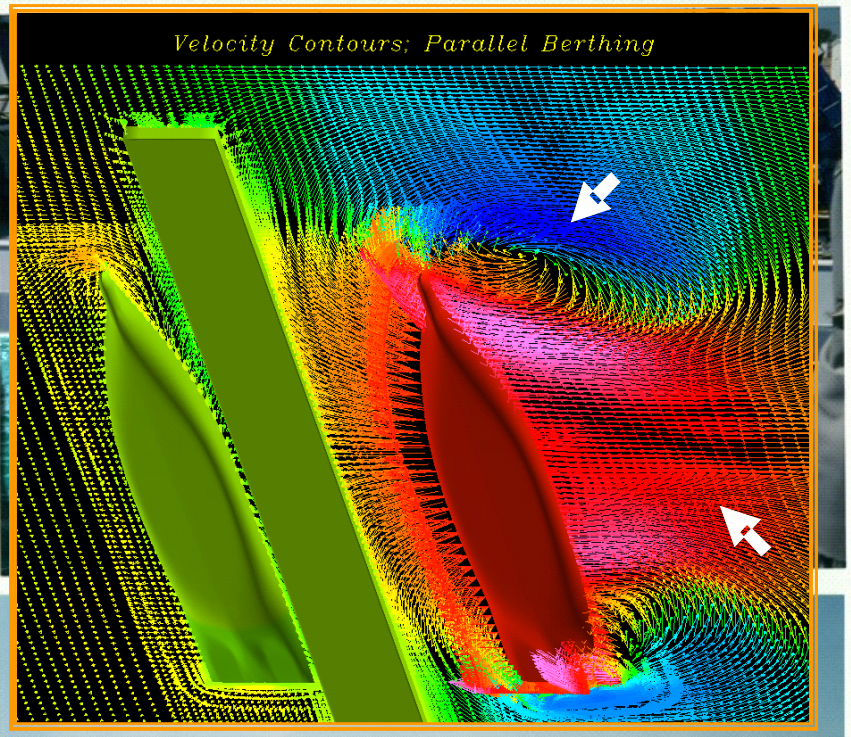
# Validation 1

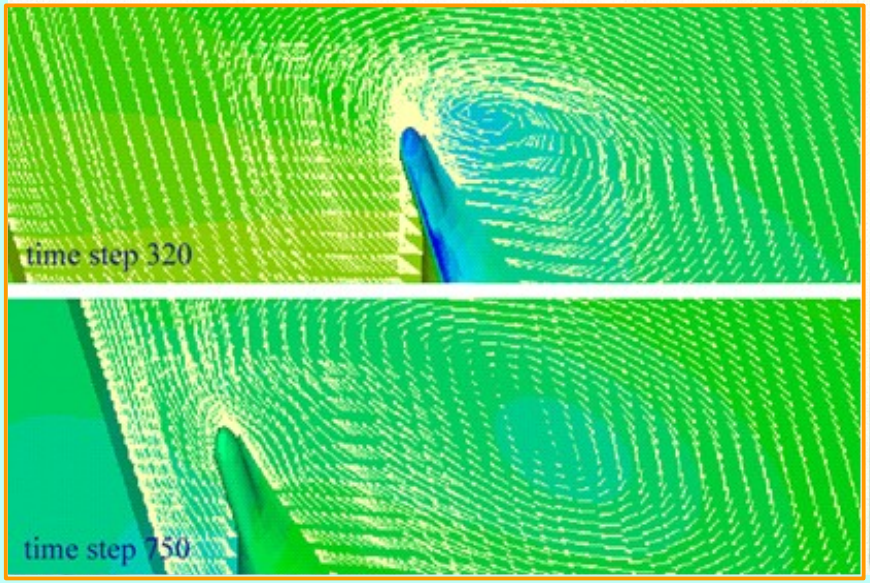
## Wave induced vorticity around a rectangular cylinder

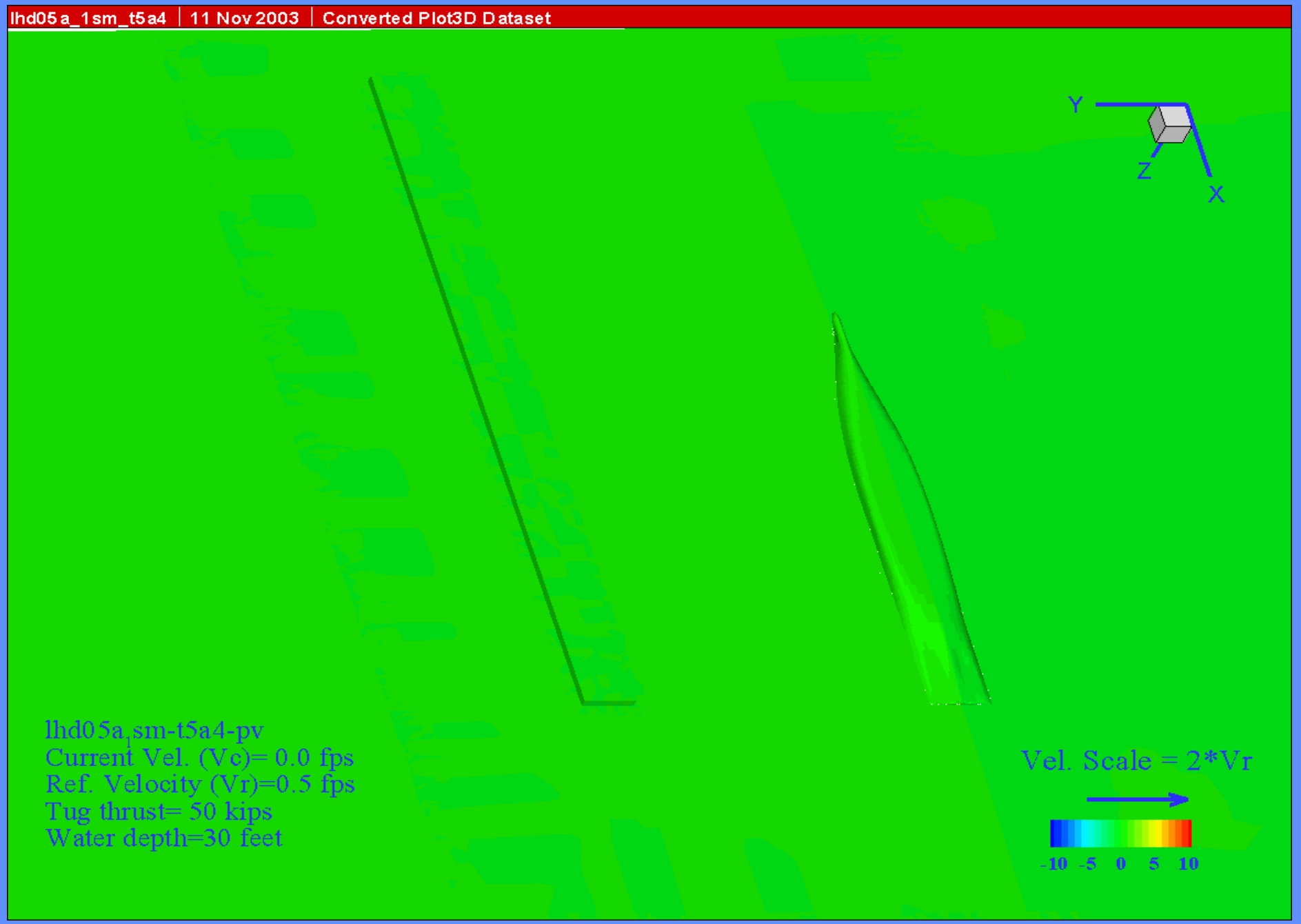


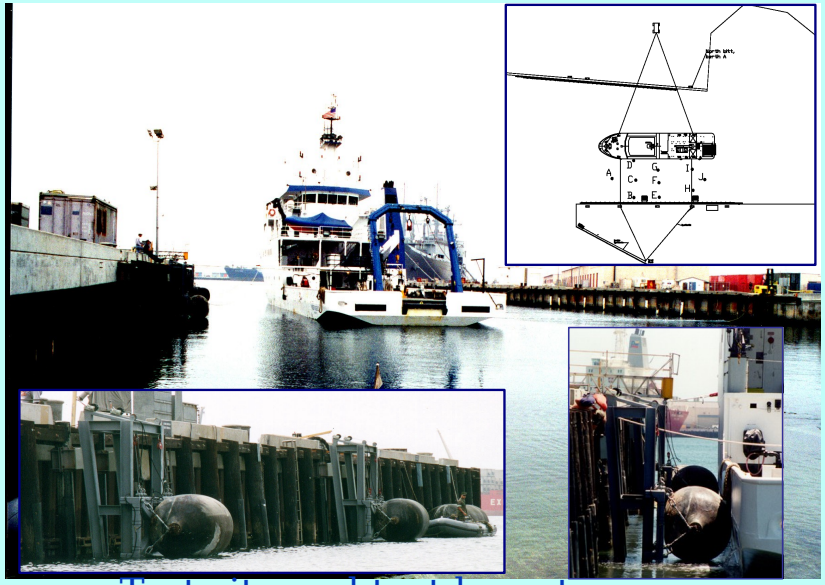
# Validation 2a: flow pattern



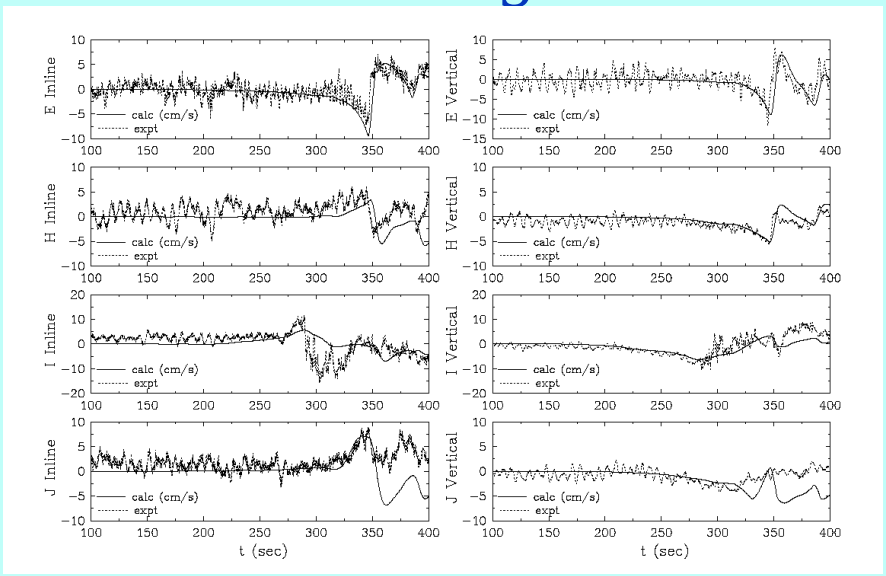




lhd05a_1sm_t5a4 | 11 Nov 2003 | Converted Plot3D Dataset
Y
Z
X
lhd05a_sm-t5a4-pv
Current Vel. (Vc)= 0.0 fps
Ref. Velocity (Vr)=0.5 fps
Tug thrust= 50 kips
Water depth=30 feet
Vel. Scale = 2*Vr
-10 -5 0 5 10

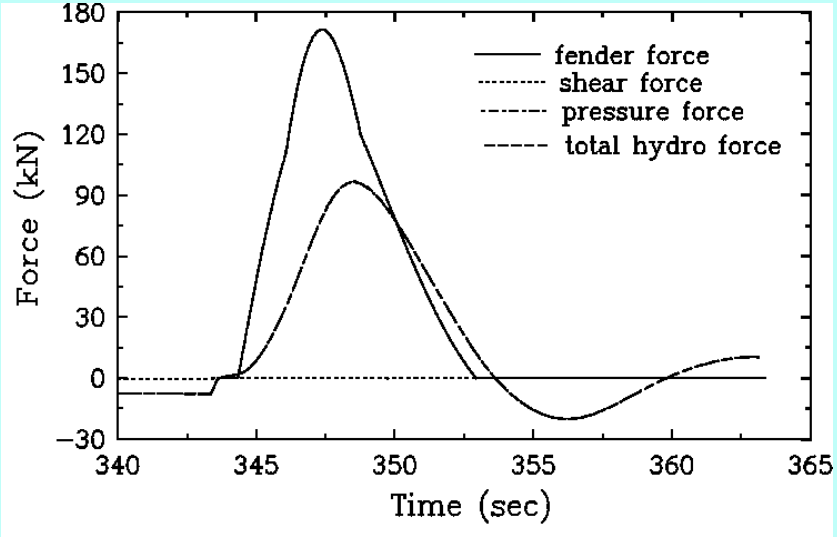
# Validation 2b: Currents and berthing loads



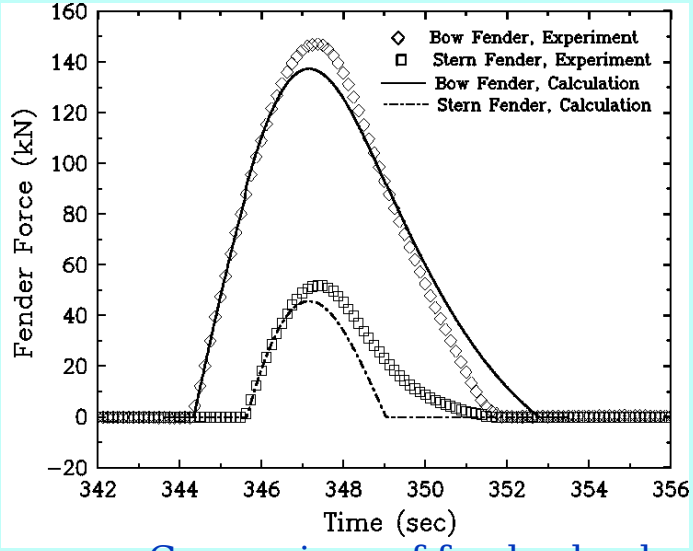
Test site and test layouts




Comparison of ship induced velocities

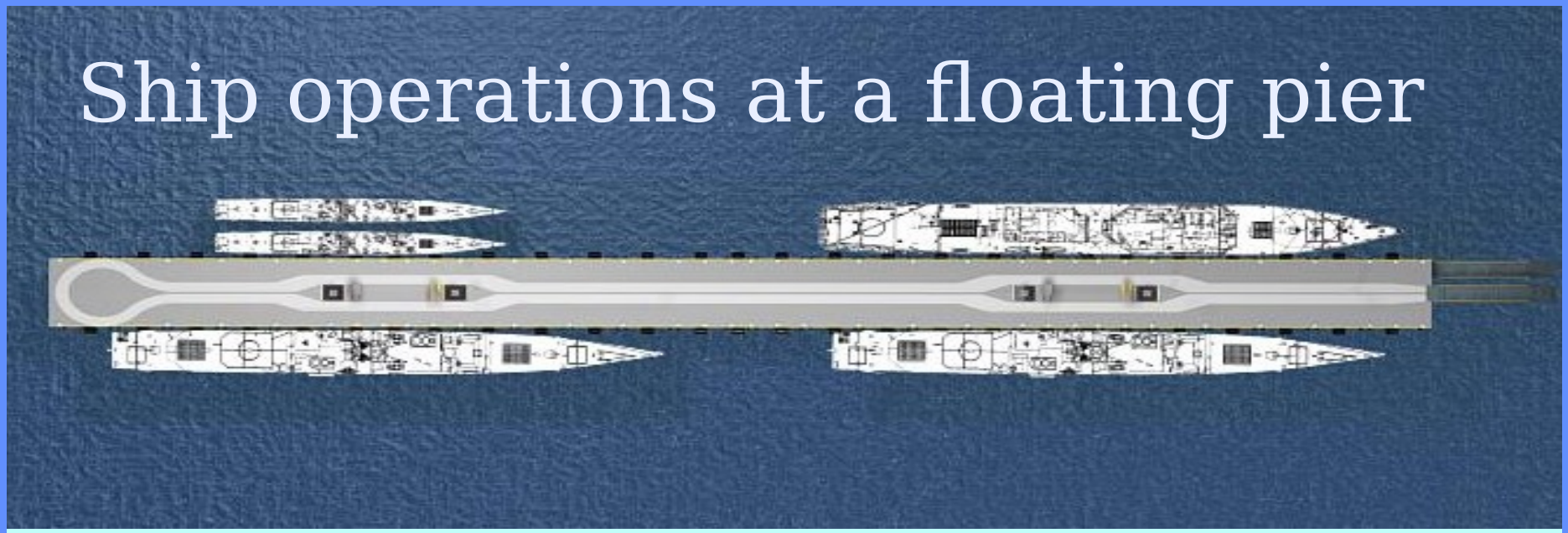


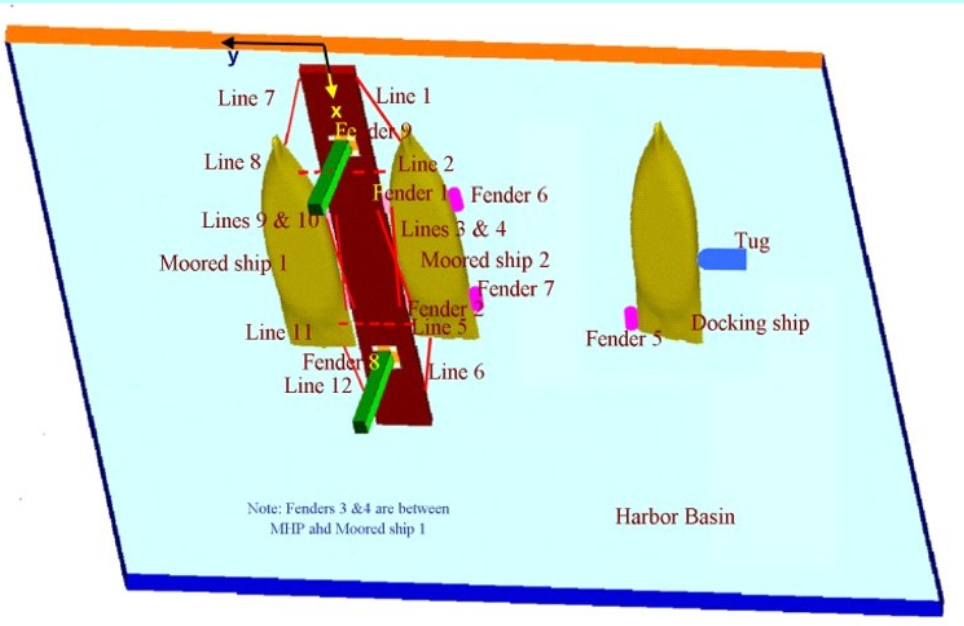

Fender loads and hydrodynamic forces




Comparison of fender loads

# Ship operations at a floating pier

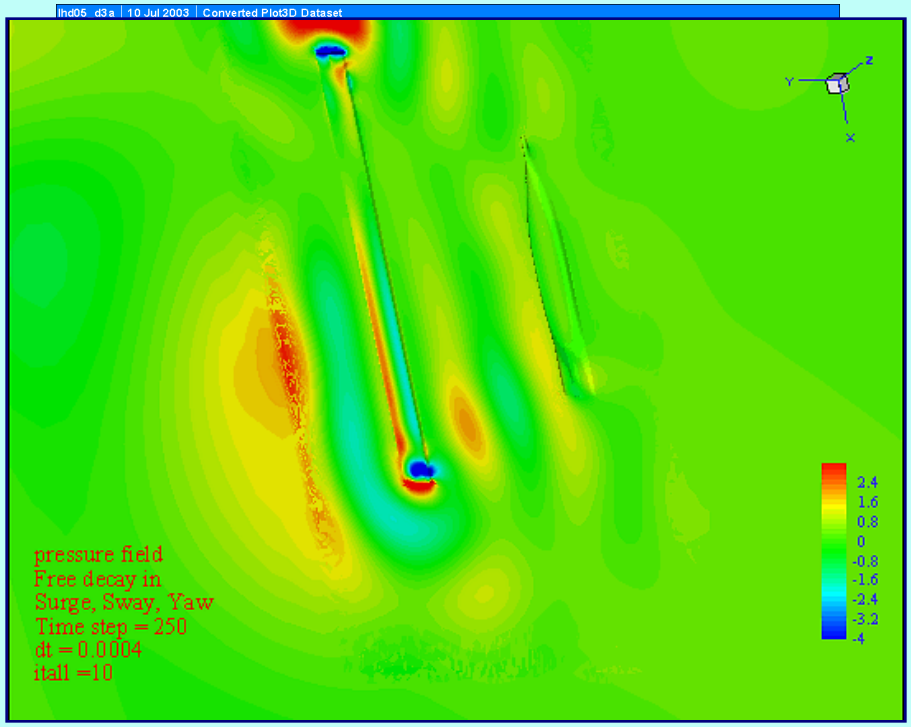


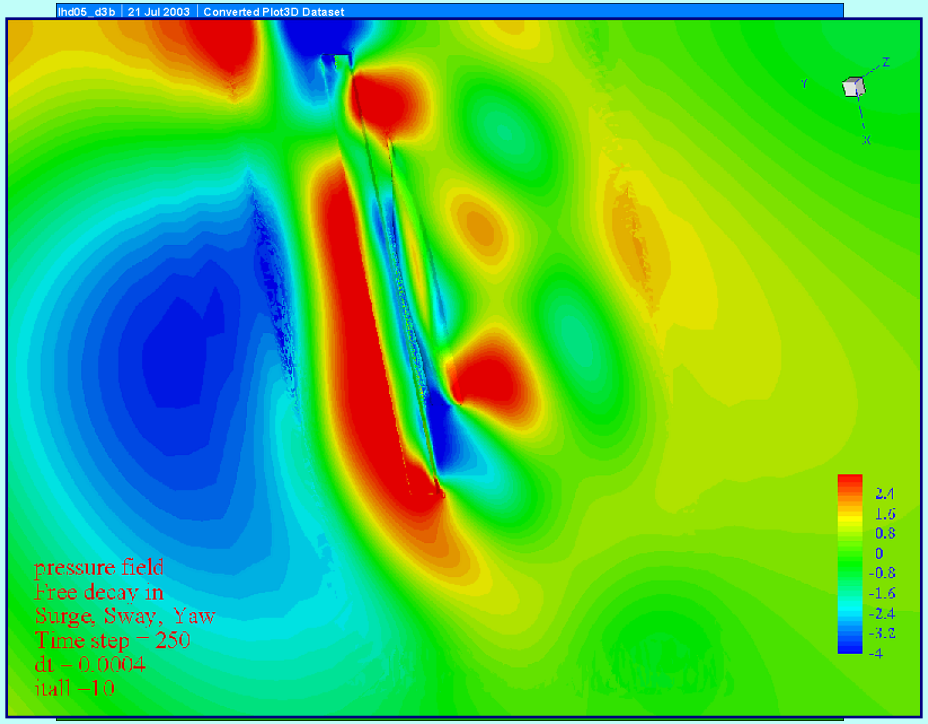


# Free Decay

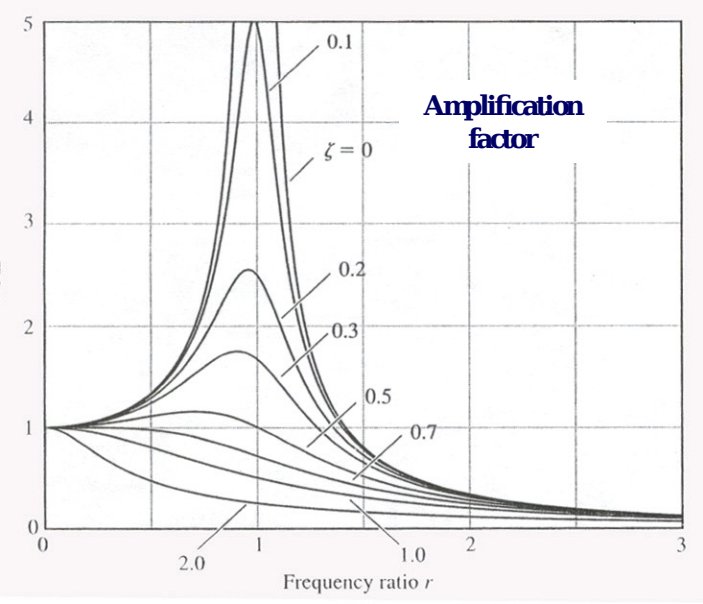
Purposes:

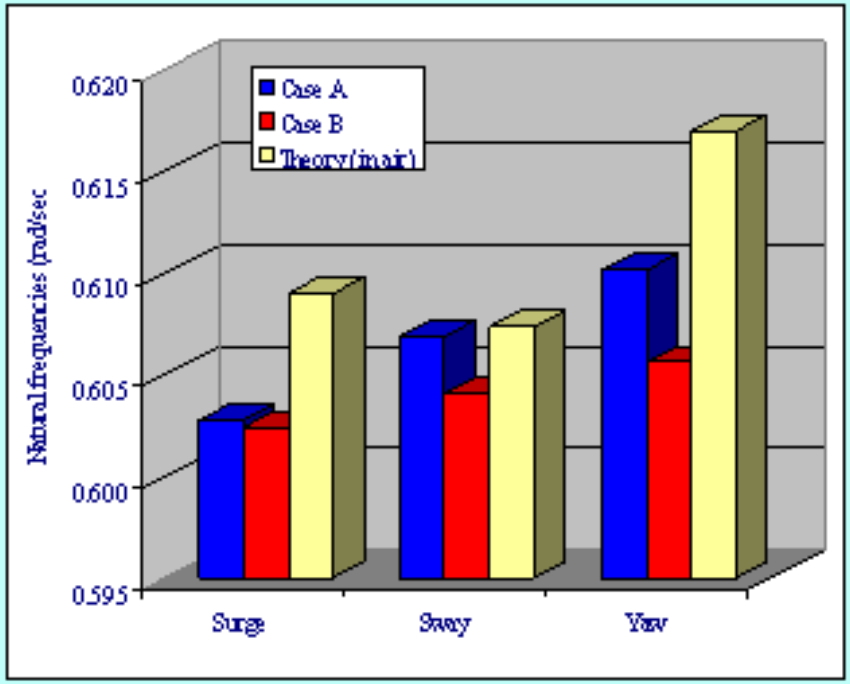
- Quantify dynamic characteristics of MHP: resonant frequency & damping
- Explore the influence of vicinity structures to the motion characteristics of MHP



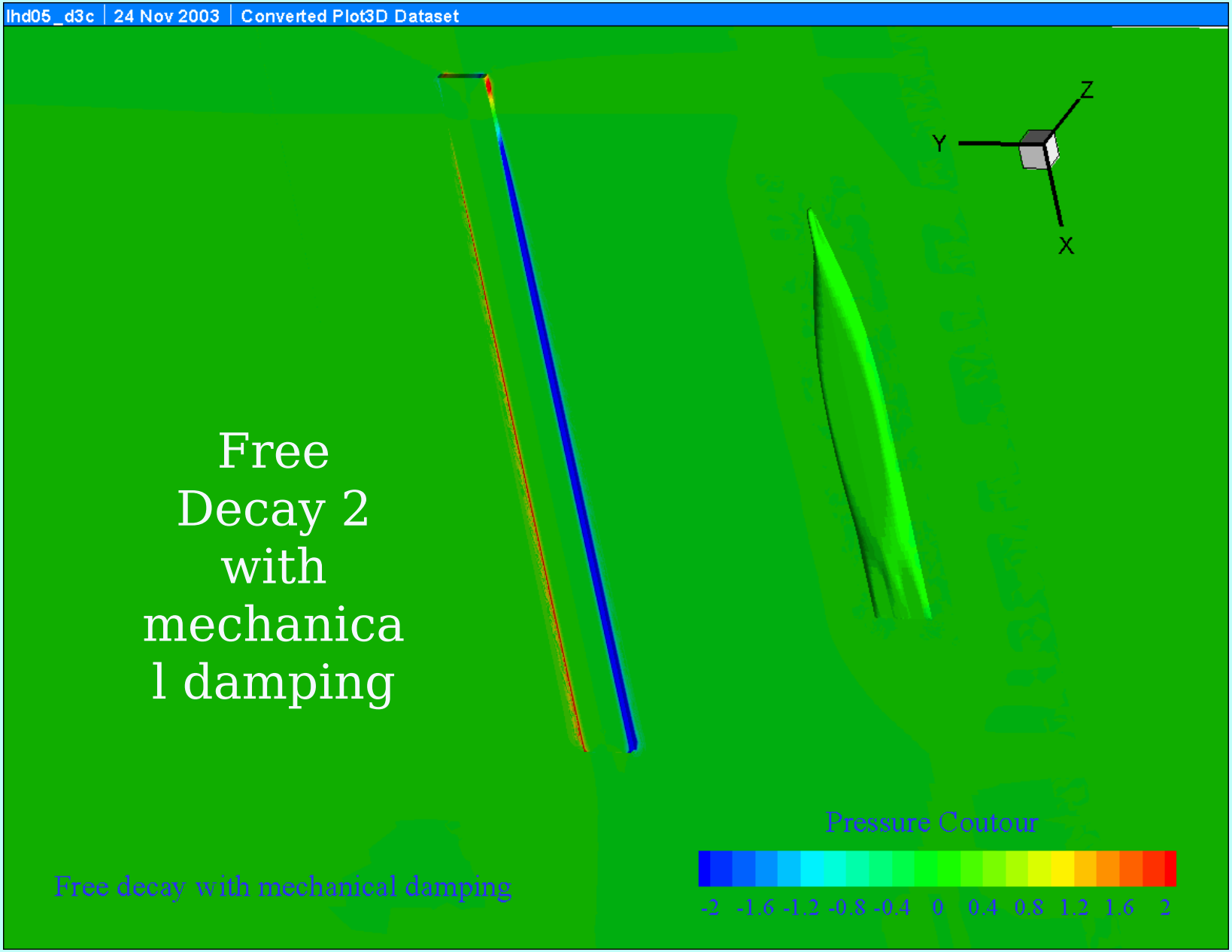



# Validation 3: Free decay/Natural frequency



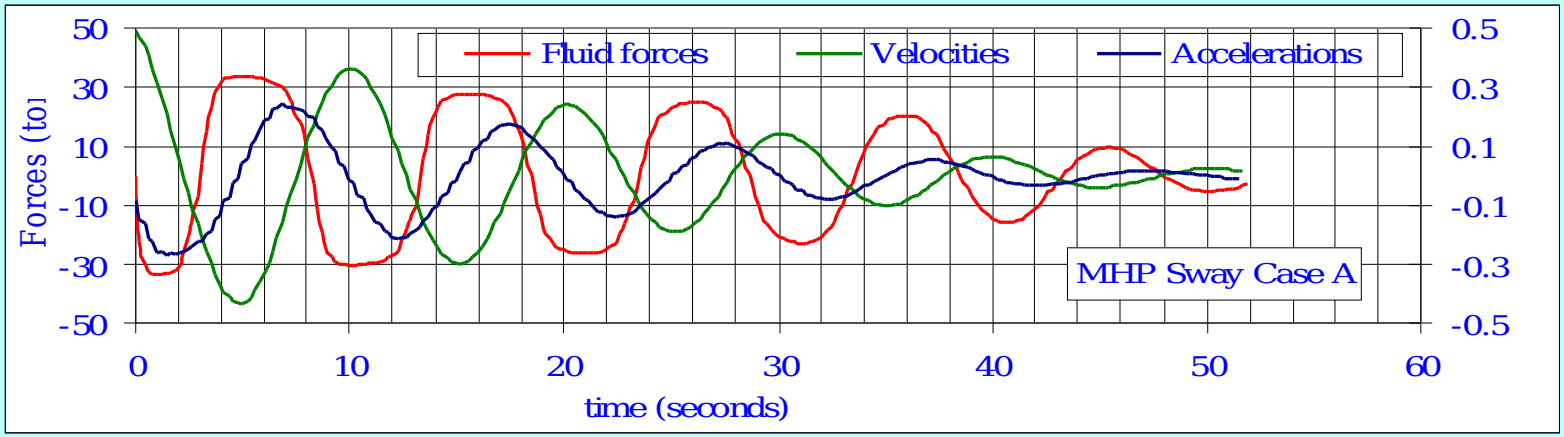



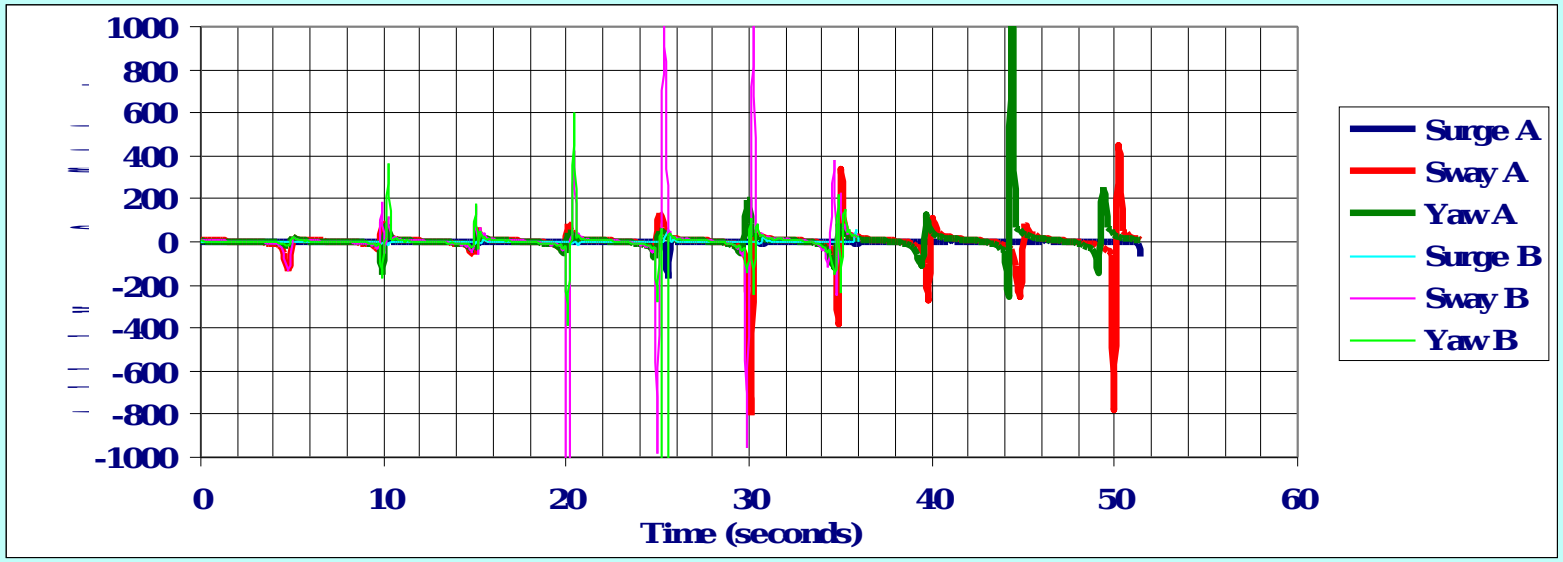

| Case ID | $\omega_*$ (in the air) Undamped frequency | | | $\omega_{d'} = \omega_* * \sqrt{(1 - \eta^2)}$ theory (Equation xx) | | | $\omega_d$ Simmulated frequency | | | $\eta$ Damping coefficient (Equation xxxx) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Surge | Sway | yaw | Surge | Sway | yaw | Surge | Sway | yaw | Surge | Sway | yaw |
| Case A | 0.609 | 0.609 | 0.618 | .609 | .607 | .617 | .603 | .607 | .610 | .0004 | .0730 | .0562 |
| Case B | 0.609 | 0.609 | 0.618 | .609 | .607 | .617 | .602 | .604 | .606 | .0004 | .0786 | .0529 |


lhd05_d3c | 24 Nov 2003 | Converted Plot3D Dataset
Z
Y
X
Free Decay 2 with mechanica l damping
Pressure Coutour
-2 -1.6 -1.2 -0.8 -0.4 0 0.4 0.8 1.2 1.6 2
Free decay with mechanical damping

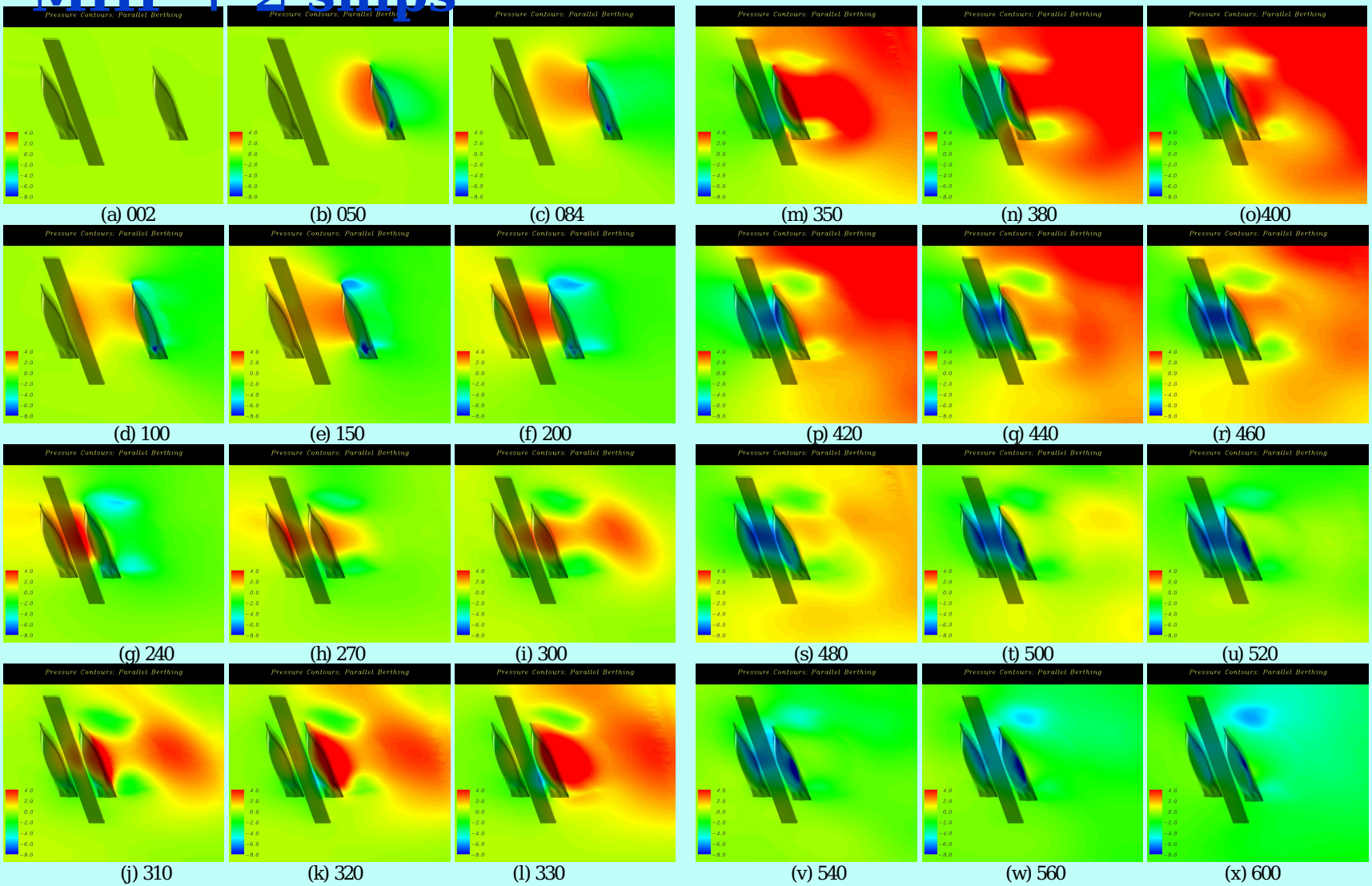
# Nature of fluid reactions

*Added mass ?*



# Hull and free surface pressure distribution: MHP + 2 ships



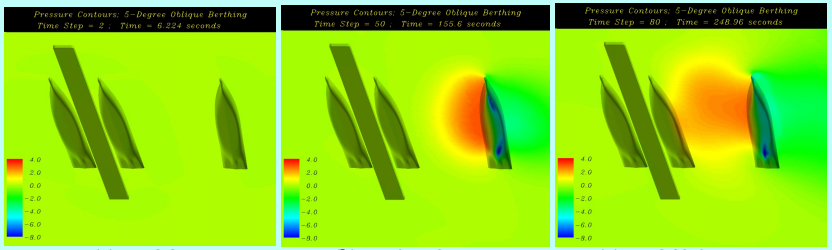

(a) 002 (b) 050 (c) 084 (m) 350 (n) 380 (o)400

(d) 100 (e) 150 (f) 200 (p) 420 (q) 440 (r) 460

(g) 240 (h) 270 (i) 300 (s) 480 (t) 500 (u) 520

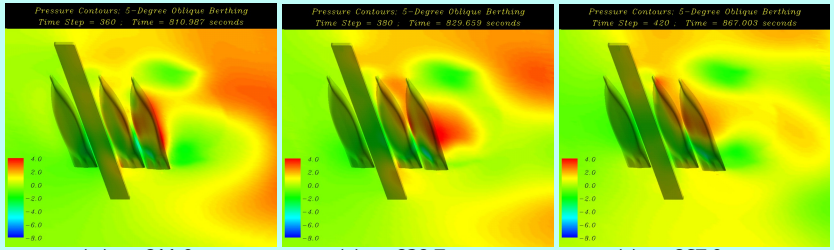
(j) 310 (k) 320 (l) 330 (v) 540 (w) 560 (x) 600

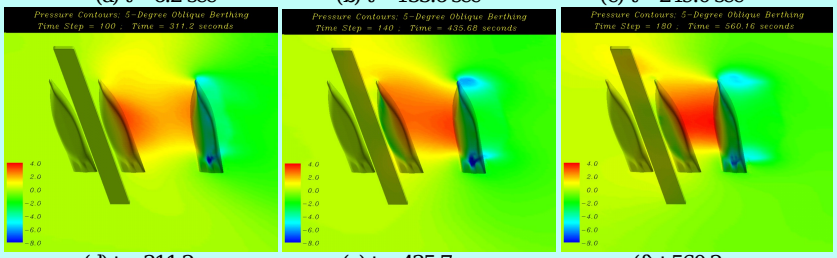
# Hull and free surface pressure distribution: MHP + 3 ships


(a) t = 6.2 sec


(b) t = 155.6 sec

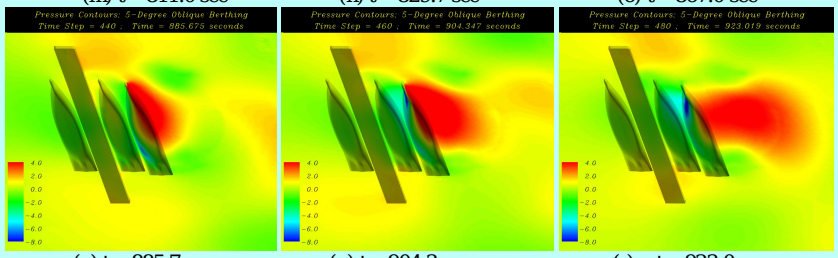

(c) t = 249.0 sec

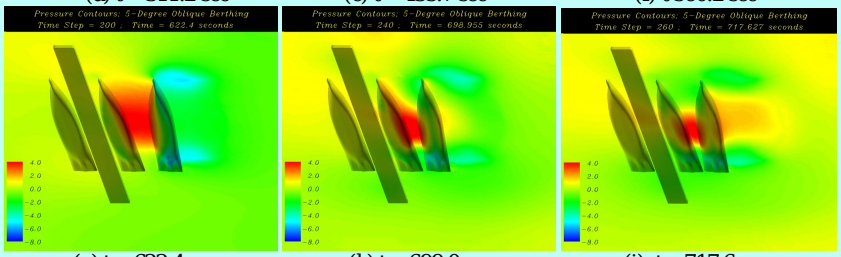

(m) t = 811.0 sec (n) t = 829.7 sec (o) t = 867.0 sec


(d) t = 311.2 sec


(e) t = 435.7 sec

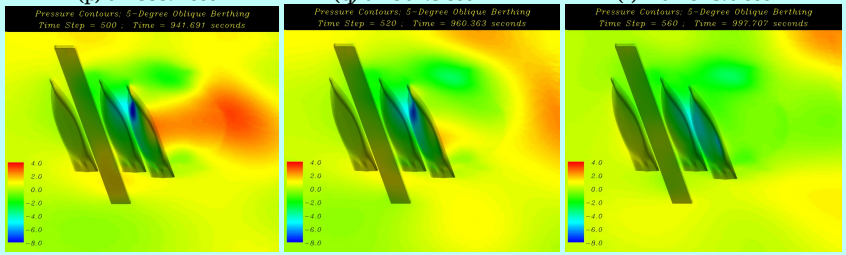

(f) t 560.2 sec

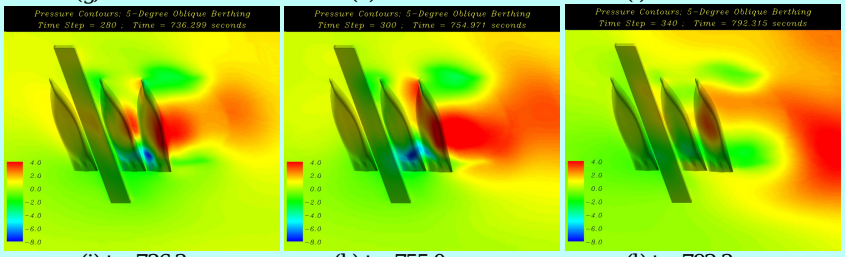

(p) t = 885.7 sec (q) t = 904.3 sec (r) = t = 923.0 sec


(g) t = 622.4 sec


(h) t = 699.0 sec

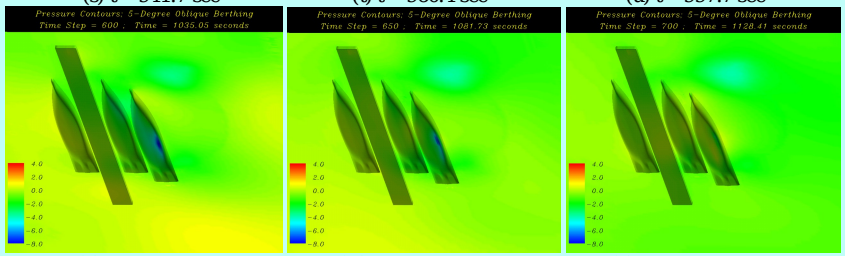

(i) t = 717.6 sec


(s) t = 941.7 sec (t) t = 960.4 sec (u) t = 997.7 sec


(j) t = 736.3 sec


(k) t = 755.0 sec


(l) t = 792.3 sec


(v) t = 1035.1 sec (w) t = 1081.73 sec (x) t = 1128.41 sec

# Provides a complete system description in detail

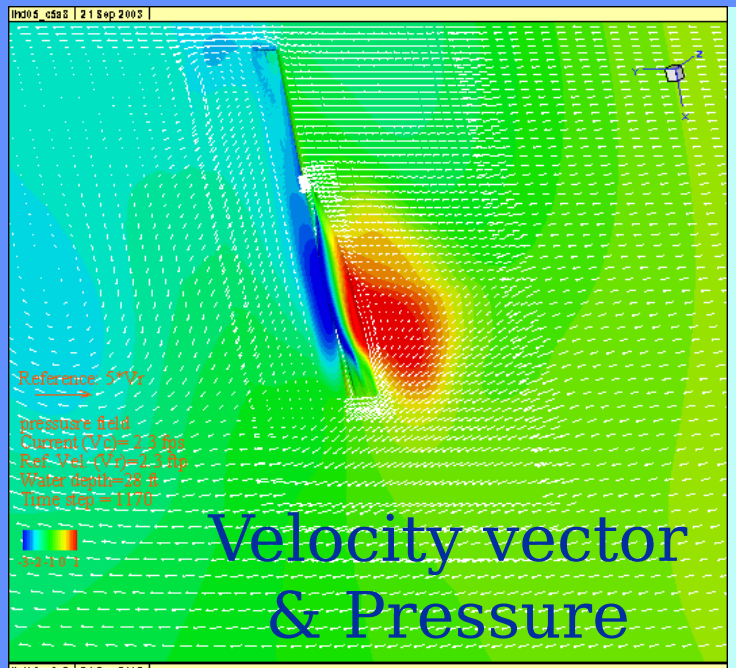
(in time domain throughout entire simulation duration)

**Fluid**

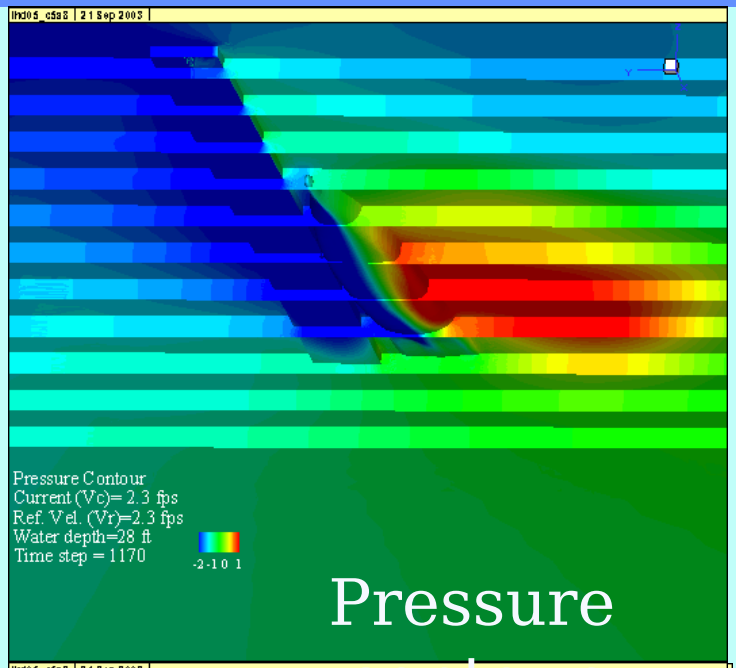
- Pressure
- Velocity (u, v, w)
- Density
- Vorticity
- Turbulence
- Surface waves

**Ship/Structure**

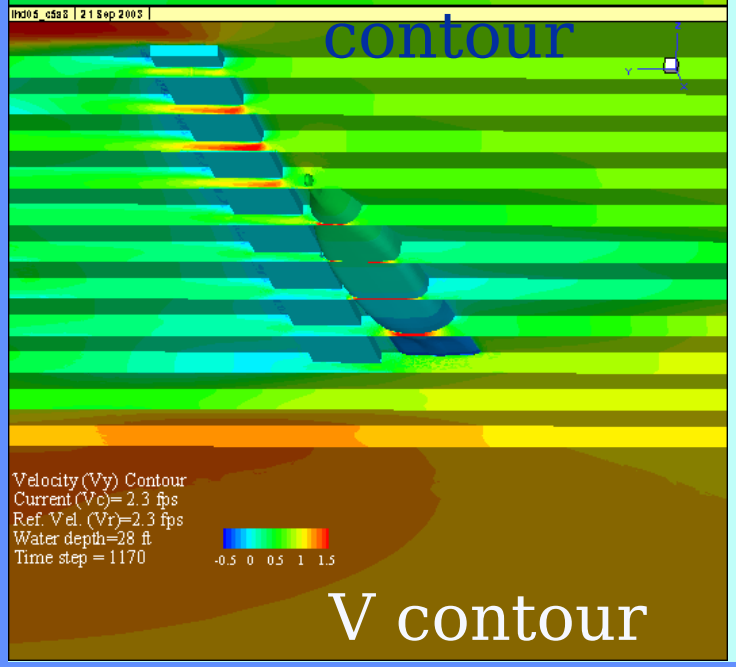
- Fluid forces
- Ship/Structure behaviors
- Relative motions
- Coupling forces
- Mooring reactions
- Overtopping/Green water



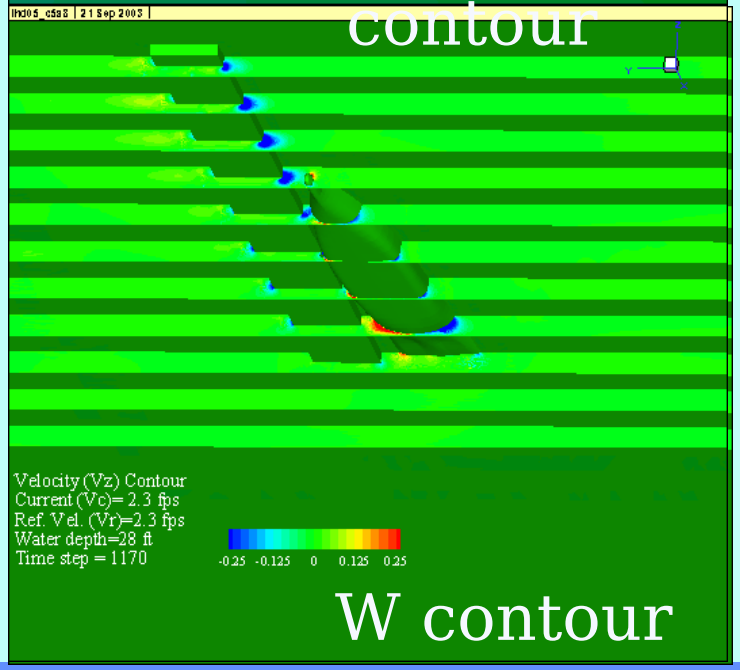

Velocity vector & Pressure contour




Pressure contour




V contour


lhd05_c5a8 | 21 Sep 2003
Velocity (Vz) Contour
Current (Vc)= 2.3 fps
Ref. Vel. (Vr)=2.3 fps
Water depth=28 ft
Time step = 1170
-0.25 -0.125 0 0.125 0.25

W contour

CASE:LHD05

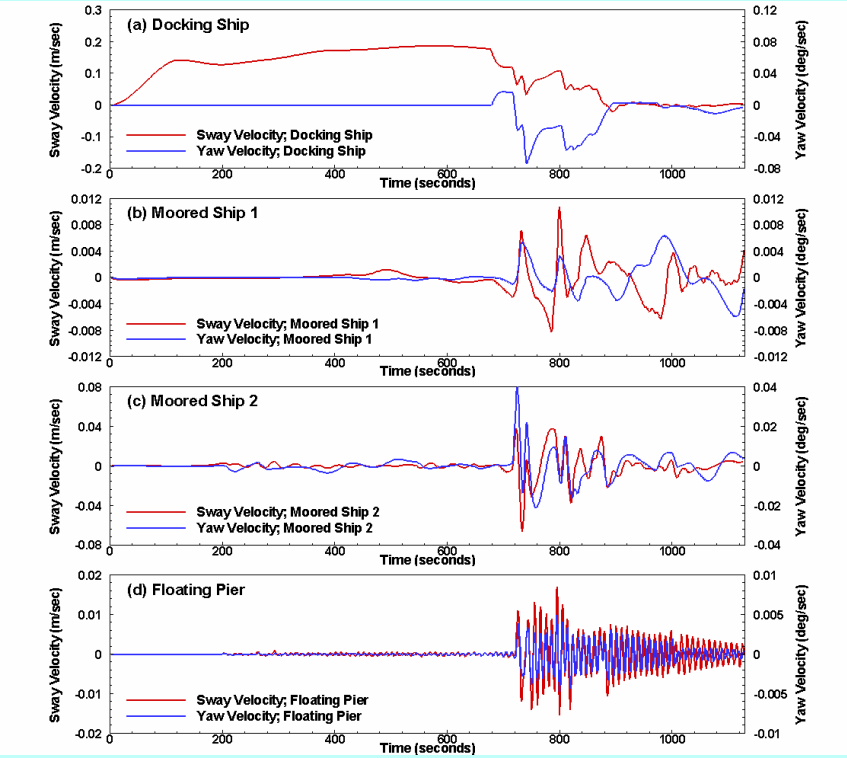
1SM_C5A8a

Water depth:28 feet

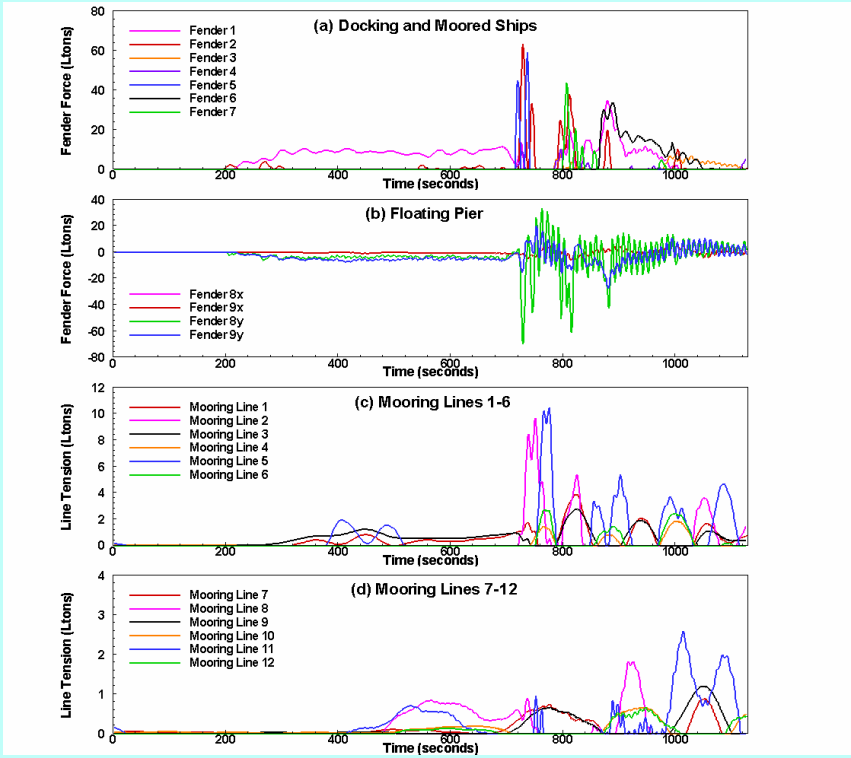
Current spd: 2.3 fps

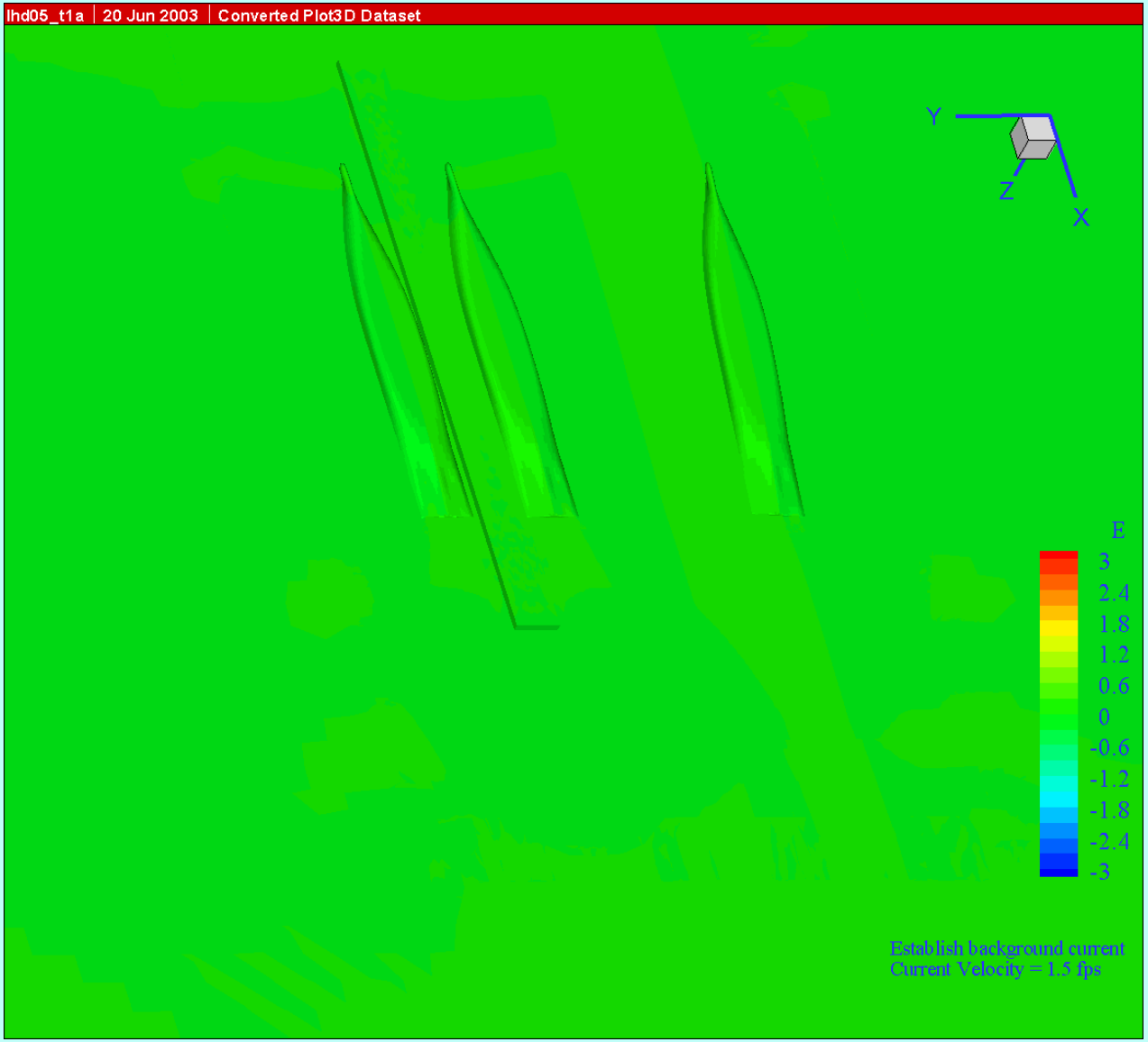
- pressure
- velocity (u,v,w)
- density
- vorticity
- turbulence

# Vessel motions




# Coupling forces






## Parameters explored

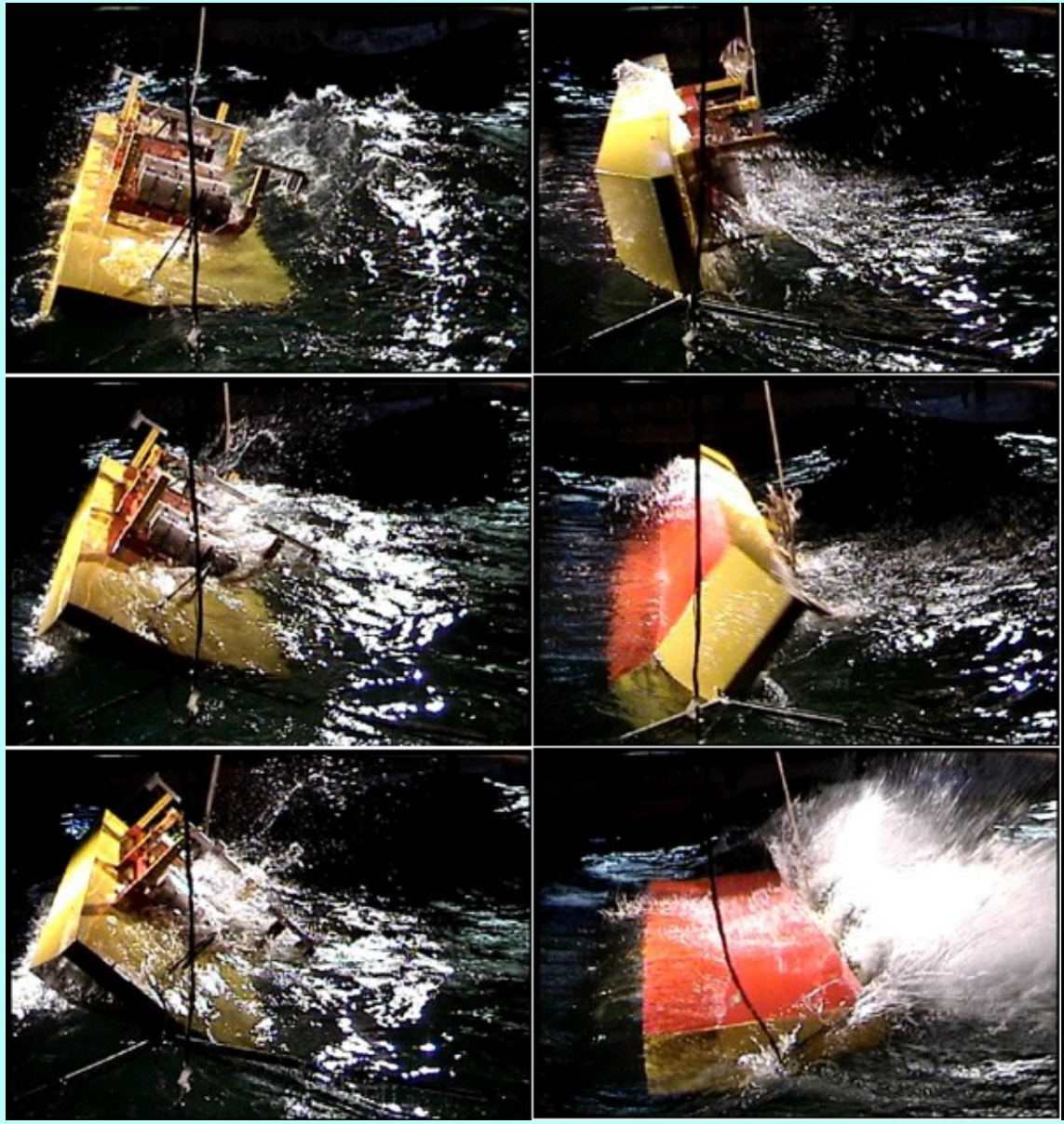
- Ship layouts
- Pier layouts
- Berthing procedures
- Coupling layouts
- Mooring features
- Water depths
- Tug thrust
- Current speeds
- Wind forces

## Stability test - Fy96

**Type:** Froude model
**Scale:** 1/8 scale of ACBL
**Scope:** stability threshold
nonlinear factors

## Test parameters

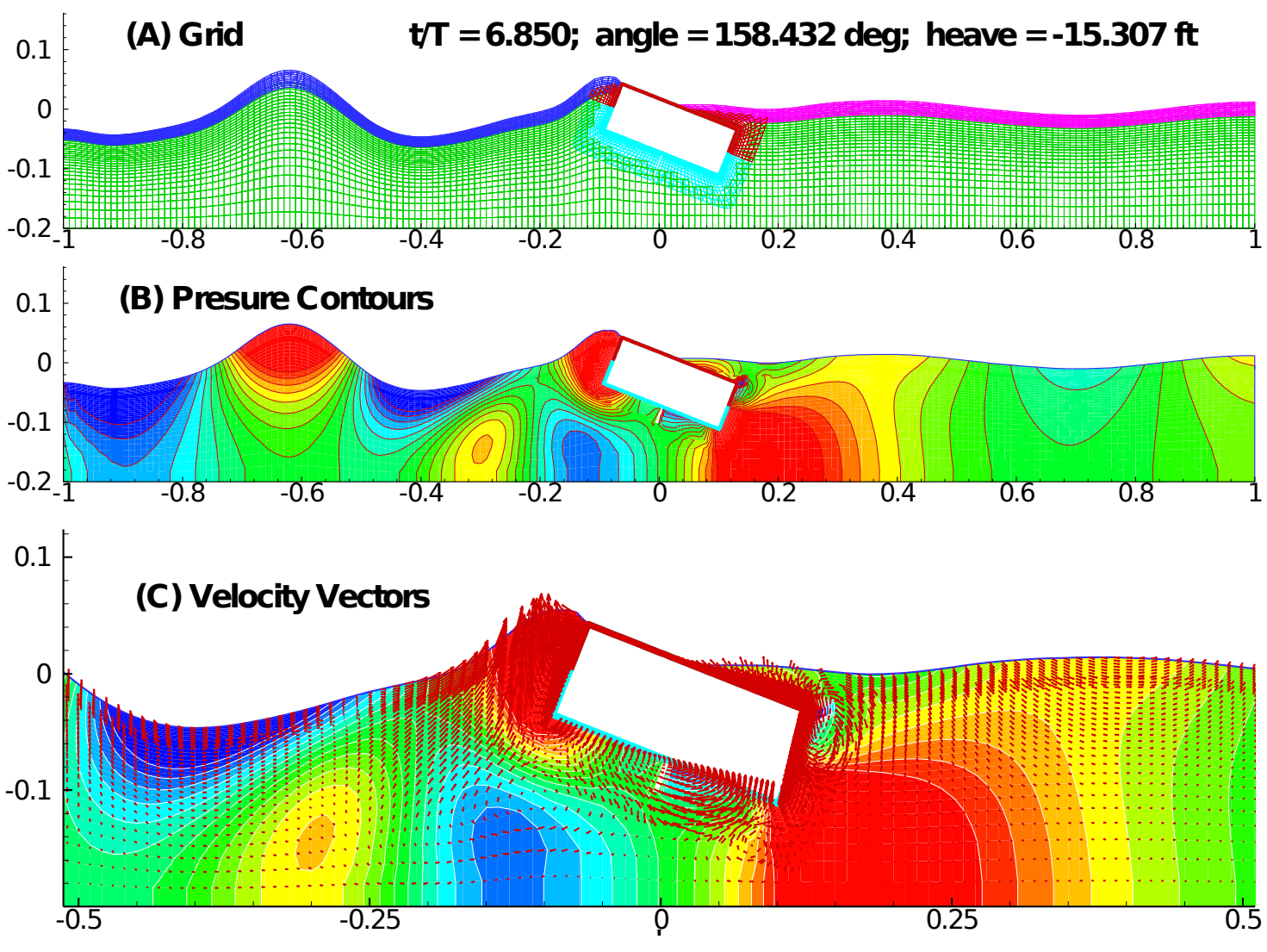
**Waves:** Swell 3-12 ft at 5-1
Storm SS4 - SS5
**Heading:** 0, 45, 90 deg.
**Draft:** 4 and 6 feet
**C. G. :** 9.13-11.30 ft above



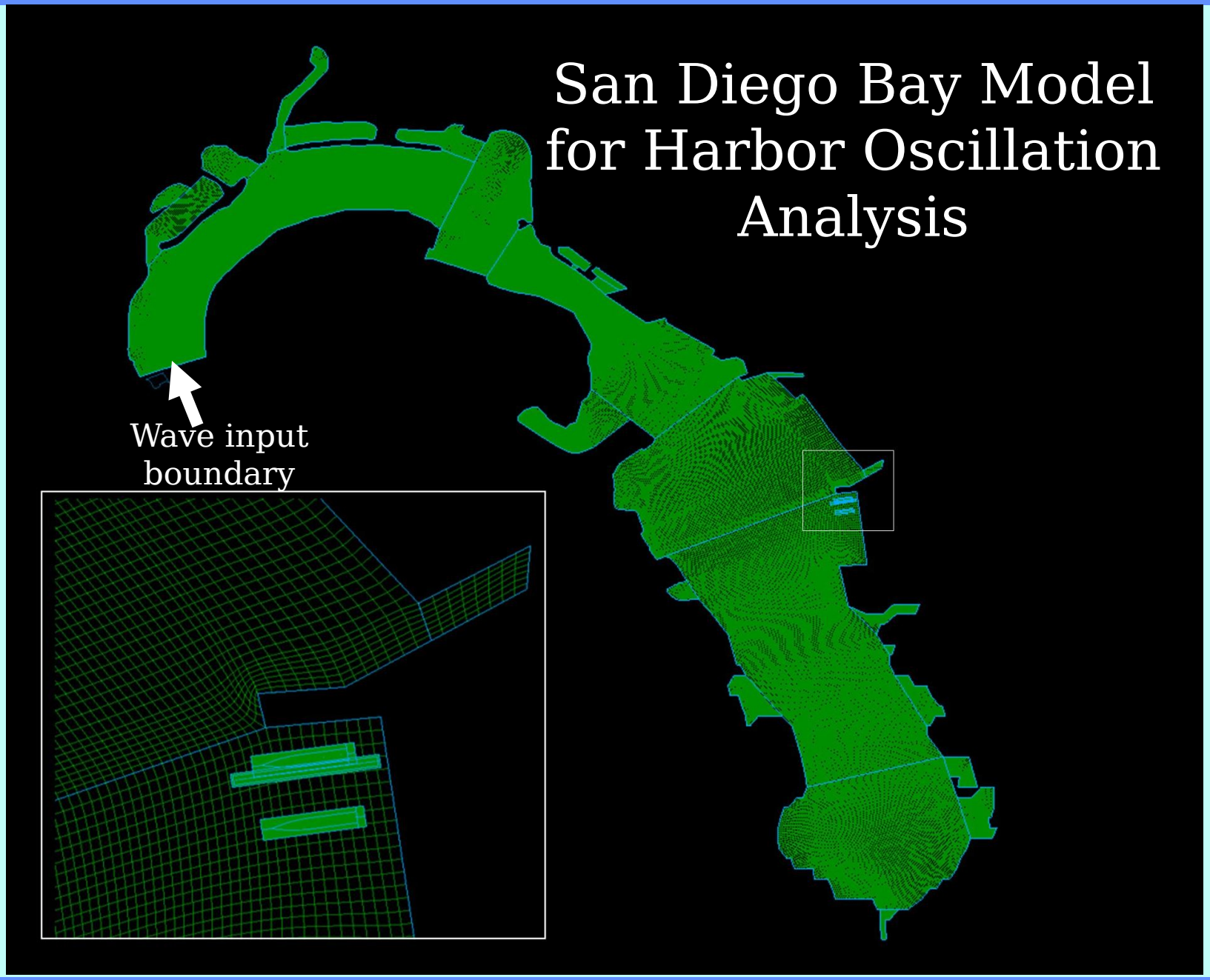
Video

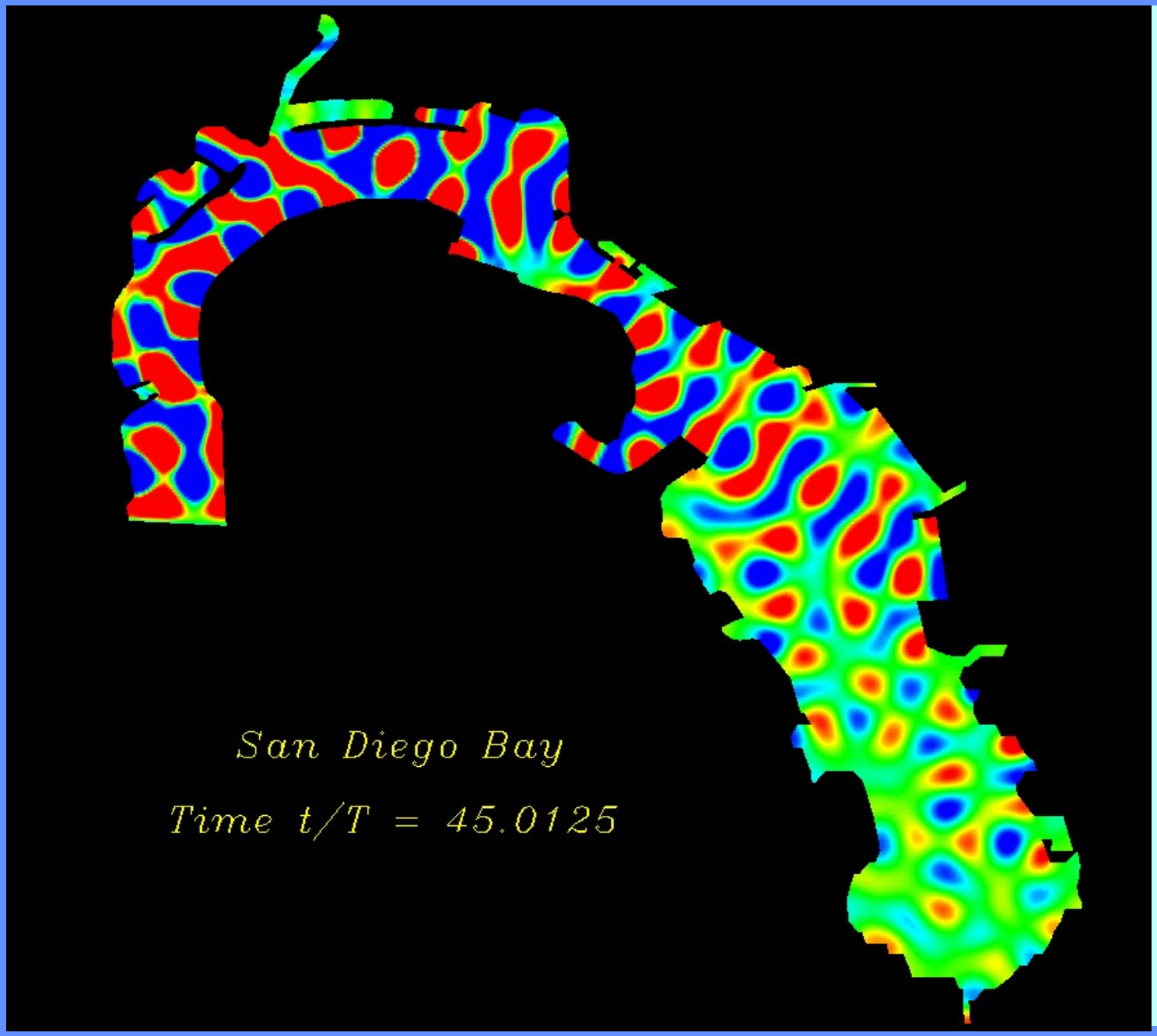
Barge capsizing: hydraulic model

# Barge capsizing: numerical simulation



# San Diego Bay Model for Harbor Oscillation Analysis





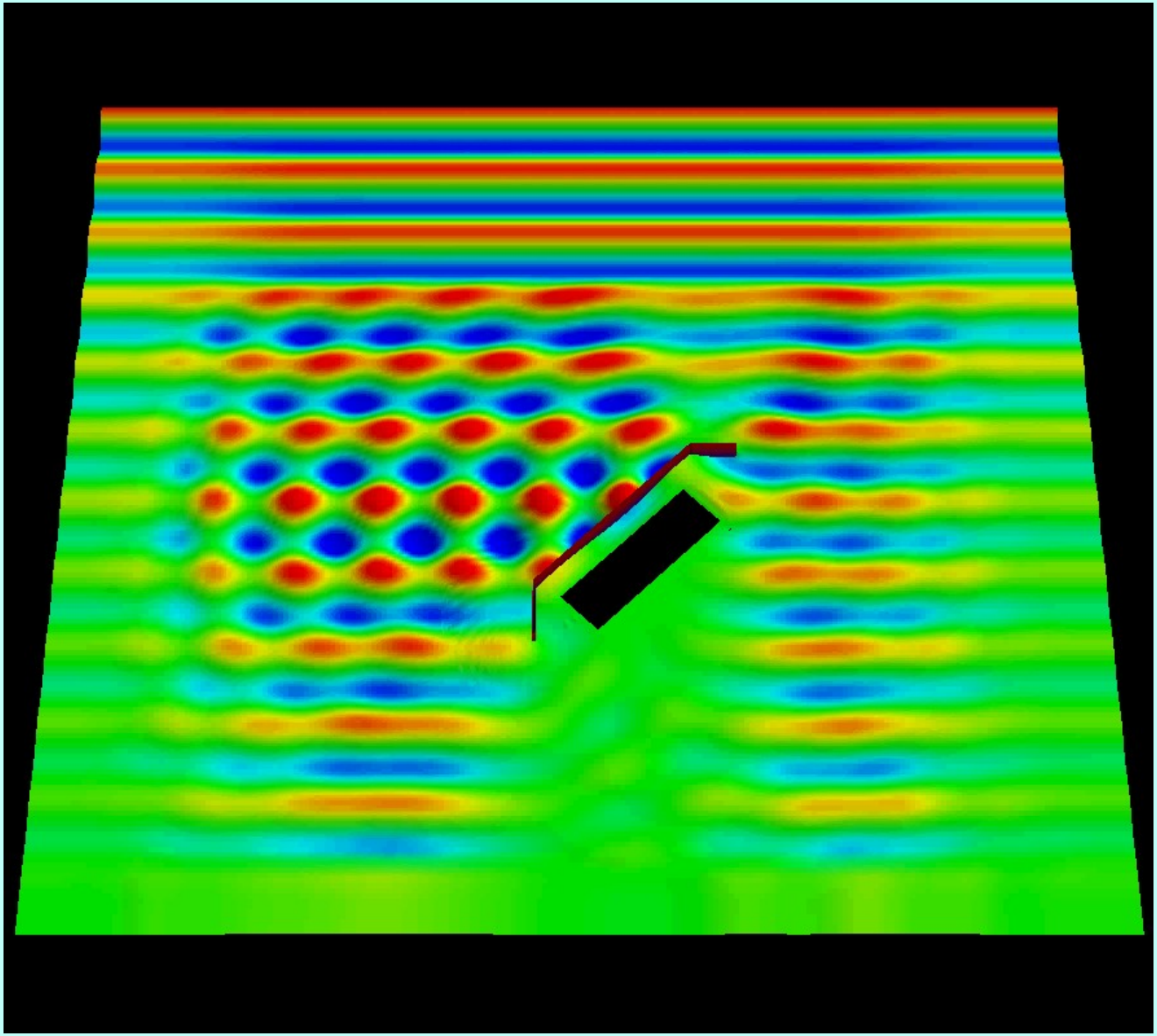

# Wave transformation in San Diego Bay

(preliminary)

Wave length: 5000 ft

Water depth: 40 ft

# Numeric al Tank



# Summary

CFD simulation

- complements experimental and theoretical fluid dynamics
- provides high-fidelity, high-resolution insights
- addresses non-existence entities
- handles non-reproducible conditions
- pertains to the entire life cycle of a system
- reduces total ownership cost

Consider viscous codes if any of the following exists.

- shallow water
- transverse motion/Beam currents
- heavily coupled multi-body system

NAVFAC
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# Q&A: